THE

VOYAGE OF H.M.S. CHALLENGER.

A SUMMARY OF THE SCIENTIFIC RESULTS.

APPENDIX (PHYSICS AND CHEMISTRY, PART VIII.)—REPORT ON OCEANIC CIRCULATION.

REPORT

ON THE

SCIENTIFIC RESULTS

OF THE

VOYAGE OF H.M.S. CHALLENGER

DURING THE YEARS 1872-76

UNDER THE COMMAND OF

CAPTAIN SIR GEORGE S. NARES, R.N., F.R.S.,

AND THE LATE

CAPTAIN FRANK TOURLE THOMSON, R.N.

PREPARED UNDER THE SUPERINTENDENCE OF

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AND NOW OF

JOHN MURRAY

ONE OF THE NATURALISTS OF THE EXPEDITION

A SUMMARY OF THE SCIENTIFIC RESULTS

APPENDIX (PHYSICS AND CHEMISTRY, PART VIII.)—REPORT ON OCEANIC CIRCULATION

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EDITORIAL NOTES.

One of the most important subjects brought into prominence by the contributions of the Challenger Expedition to the Science of Oceanography was that of Oceanic Circulation. It is possible to observe directly the rate and direction of the surface currents of the ocean, and, by means of current drags and other instruments, to gather some information with regard to the motion and direction of undercurrents at no great distance beneath the surface in some parts of the ocean, such as, for instance, the Strait of Gibraltar and the Bosphorus. In the greater depths of the ocean the motion of the water is too slow for observations of this nature, and it becomes necessary to trace movements by a study of the temperature and specific gravity of the ocean waters.

As the examination of the Challenger observations bearing on the question of oceanic circulation proceeded, it became apparent that a full discussion of atmospheric circulation was required as a necessary preliminary. Accordingly I induced Dr. Alexander Buchan to undertake the preparation of a Report on Atmospheric Circulation based on the Challenger and other available meteorological observations, and a Memoir on this subject was published five years ago. Shortly afterwards Dr. Buchan commenced the discussion of the data bearing on oceanic circulation, the most important of these being the Challenger observations. All other published data obtainable has been made use of in the discussion, and, in addition, a large amount of unpublished data was placed at Dr. Buchan's service by the Meteorological Council and by Admiral Wharton, Hydrographer of the Admiralty. The preparation of this Memoir has occupied the whole of the time at Dr. Buchan's disposal

during the past five years, and has been a peculiarly heavy piece of work. It involved a search for all available material, extracting the observations and reducing them to uniform standards, charting them thereafter on a large number of maps, a selection only of which are published with this Report. Much time was required in the preparation of the maps, Nos. I. and II., which exhibit the mean annual temperature and specific gravity of the surface of the ocean. The practice of including annual means in their published tables and maps of sea-temperatures and salinities has been hitherto seldom adopted by meteorologists, consequently it was necessary to calculate these means where possible, since it is from such alone that any satisfactory discussion of the temperature and specific gravity of the ocean at all depths can proceed.

The present Report is divided into two parts, the first dealing with the surface of the ocean, and the second with the deeper ocean waters. The former gives a brief *résumé* of those atmospheric conditions which bear on the question, particularly the distribution of pressure and the prevailing winds dependent on the pressure. Attention is pointedly drawn to the intertropical distribution of pressure and the area within this region where pressure is lowest, since the position of this area or band with reference to the equator appears to give the key to the solution of the problems under consideration, viz., whether any of the surface currents of the ocean, generated and maintained by the trade winds, cross the equator, bearing with them a high temperature and high specific gravity into another hemisphere than that in which they had their origin. The relation of the prevailing winds to the great currents of the ocean is pointed out as well as the relation of the rainfall to the specific gravities. The distribution of the temperature of the surface of the ocean and of its specific gravity is fully described and illustrated on the first two maps. On twenty-seven maps the temperatures of the sea at 10, 15, 20, 25, 30, &c., fathoms down to 200 fathoms were entered with the view of ascertaining approximately the depth

at which the influence of season is no longer felt on the open ocean. This depth was provisionally fixed at 100 fathoms, and it is of importance to note that at this and greater depths each observation of temperature and specific gravity may be treated as a good annual mean.

The second part of the Report examines the temperatures and specific gravities at depths from 100 fathoms to the bottom, their relations to the temperatures, specific gravities, and currents near the surface, and the horizontal and vertical movements of the ocean in this way indicated. The results, so far as now ascertained, point unmistakably to the necessity for further exploration of the Southern Ocean, the western half of the South Atlantic, and the Pacific from about long. 150° W. to the American coasts, before completely satisfactory explanations can be given for some of the phenomena pointed out in the Memoir.

It will be seen, however, that Dr. Buchan has made a most important contribution to knowledge, which will be welcomed by all who take an interest in the science of the sea.

The Report is illustrated by sixteen double-page maps. The manuscript was received by me in December 1894.

JOHN MURRAY.

CHALLENGER OFFICE, 45 FREDERICK STREET,
EDINBURGH, *January* 12, 1895.

THE

VOYAGE OF H.M.S. CHALLENGER.

PHYSICS AND CHEMISTRY.

REPORT on Oceanic Circulation, based on the Observations made on board H.M.S. Challenger, and other Observations. By Alexander Buchan, M.A., LL.D., F.R.S.E.

During the two or three years preceding the time when the Challenger left on her famous voyage, several large questions, both practical and scientific, affecting the general movements of the atmosphere and the ocean began to be discussed, with an intelligence and fulness new to the discussion of such questions. These discussions were occasioned by the correct deep-sea temperatures which then began to be obtained, and by a first approximate representation of the distribution over the earth of the mass of the earth's atmosphere, thus leading to a more accurate knowledge of the prevailing winds of the globe resulting from that distribution. At that time, any discussions that were attempted on the more fundamental problems of meteorology, relative to the diurnal and seasonal changes in atmospheric temperature, pressure, humidity, and wind, were really restricted to observations made on land. It was plain that data obtained exclusively from observations made on land, which occupies little more than a fourth part of the earth's surface, were inadequate to a right conception and explanation of atmospheric phenomena.

Accordingly, when the Challenger Expedition was fitted out in 1872, arrangements were made for taking, during the cruise, either hourly or two-hourly observations both of atmospheric phenomena and of the surface temperature of the sea; and in addition, elaborate observations of sea temperatures and specific gravities of the sea-water at all depths. Immediately on publication in the Preliminary Reports of the Expedition, the results of these observations were at once recognised to be of first importance in terrestrial physics, inasmuch as they opened up for discussion the broad question of oceanic circulation on a basis of accurate facts.

It became more and more evident, as the examination of the results was proceeded with, that, for a right understanding of the questions raised, a full discussion of atmospheric phenomena was required as a necessary preliminary. Now, of these

phenomena the most important is an approximately correct representation of the circulation of the atmosphere over the surface of the globe in all seasons of the year. The only way by which this knowledge can be obtained is by the geographical distribution of the mass of the earth's atmosphere, as shown by mean isobaric lines, which, as is recognised, ultimately depend on the geographical distribution of the temperature and humidity of the air. Observation abundantly shows that it is the isobaric lines which absolutely rule the direction of the prevailing winds.

A discussion, therefore, of all available information relative to the different atmospheric phenomena, with more special reference to the work of the Challenger, was undertaken in 1882, and the results were published in the beginning of 1890.[1] That Report gives, in addition to the results of the Challenger observations, the mean diurnal variations of atmospheric pressure at 147 places in all parts of the globe; the mean monthly and annual pressure at 1366 places; a similar table of mean temperatures at 1620 places; and the mean monthly and annual direction of the wind at 746 places. Owing to the all-importance of the wind on oceanic circulation, other data were obtained and utilised in constructing the maps, which had been published by the marine and meteorological departments of the United States, England, France, Holland, Germany, Norway, Denmark, Italy, Mauritius, and India. A first attempt was also made to investigate and describe the meteorology of the ocean.

Among the more important factors of ocean meteorology that bear more directly on this discussion are the large permanent anticyclonic areas over the oceans, out of which the winds blow in all directions towards and over all surrounding regions where atmospheric pressure is lower. These are the regions of the oceans where calms and light winds are of most frequent occurrence. Since this state of things necessarily implies vast accessions of air setting towards these anticyclonic regions as upper aerial currents, and thence slowly descending to the surface of the sea, it follows that in these regions the air is relatively very dry; and this being so, evaporation is very great, and the specific gravity of the surface water of the sea consequently also large in anticyclonic regions.

An examination of the anticyclones and their relative prevailing winds on the isobaric maps accompanying the Report on Atmospheric Circulation, already cited, indicate that these regions may be regarded, in a very large degree, as the ORIGINS OF THE WINDS and surface currents on the sea. It is of the greatest importance to note, in connection with the specific gravity of the surface water, that the less space the winds have traversed the ocean from their origins in the anticyclonic regions, the less is the rainfall. And on the other hand, the greater the distance the winds have traversed the ocean, the more copious is the rainfall. To take examples: The isobaric lines and winds for July show that the regions of the globe where at this time of the year the

[1] Report on Atmospheric Circulation, based on the Observations made on board H.M.S. Challenger, and other Meteorological Observations, by Alex. Buchan, M.A., LL.D. (Phys. Chem. Chall. Exp., pt. v., 1889).

rainfall is large, are India, the winds arriving there having really traversed the ocean from near latitude 30° S.; the United States, the winds arriving there after having traversed nearly the whole breadth of the Atlantic and the Gulf of Mexico; and more particularly China and Japan, on which coasts the winds arrive after having traversed more than half the breadth of the Pacific. The numerous East India islands scattered over the Western Pacific very largely, in proportion to their mountainous character, increase the rainfall, especially in the equatorial region. This greatly reduces the specific gravity of the surface waters, which, in turn, has important bearings on the distribution of deep-sea temperatures in the respective regions. The West India Islands have a similar influence in lowering the specific gravity of the surface over that portion of the Atlantic. On the east coast of South America the winds blow directly home on the continent, but, as they cross no extensive island groups on their way, the specific gravity of the sea is not reduced, as happens off the south-east coast of Asia. But to the south of Monte Video the prevailing winds are no longer from the sea, but they blow from the land seawards, being within the large region swept by the north-westerly winds of the southern hemisphere; and, as will appear farther on, with marked dissimilar effects on the temperature and specific gravity of the ocean off these coasts.[1]

[1] The temperature observations utilised in preparing the maps which accompany this Report are noted below :—

1. Report on the Deep-Sea Temperature Observations obtained by the Officers of H.M.S. Challenger, during the years 1873–76 (Phys. Chem. Chall. Exp., pt. iii., 1884).

2. Preliminary Report of the Scientific Exploration of the Deep Sea in H.M. Surveying-vessel "Porcupine," during the summer of 1869, conducted by Dr Carpenter, V.P.R.S., Mr J. Gwyn Jeffreys, F.R.S., and Prof. Wyville Thomson, LL.D., F.R.S. (*Proc. Roy. Soc.*, vol. xviii. p. 397, 1869).

3. Report on Scientific Researches carried on during August, September, and October 1871 in H.M. Surveying Ship "Shearwater," by William Carpenter, M.D., LL.D., F.R.S. (*Proc. Roy. Soc.*, vol. xx. p. 535, 1871).

4. The Annual Lists of Oceanic Depths and Serial Temperature Observations of the Hydrographic Department, Admiralty, London. In addition to these, Captain Wharton, the hydrographer, placed at my service all the unpublished data in the hydrographic office.

5. The Norwegian North Atlantic Expedition, 1876–78: the North Ocean, its Depths, Temperature, and Circulation, by Prof. H. Mohn, Christiania, 1887.

6. Three Cruises of the United States Coast and Geodetic Survey Steamer "Blake," in the Gulf of Mexico, in the Caribbean Sea, and along the Atlantic Coast of the United States from 1877 to 1880, by Alexander Agassiz, Boston and New York, 1888 (*Bull. Mus. Comp. Zoöl.*, vols. xiv. and xv.).

7. Reports on the Dredging Operations off the West Coast of Central America to the Galapagos, to the West of Mexico, and in the Gulf of California, in charge of Alexander Agassiz, carried on by the U.S. Fish Commission Steamer "Albatross," Lieut.-Commander Z. L. Tanner, U.S.N., commanding (*Bull. Mus. Comp. Zoöl.*, vol. xxiii. p. 1, 1892).

8. Deep-sea Sounding and Serial Temperatures in the North Pacific Ocean, obtained 1873–74 in the United States Steamer "Tuscarora," Commander George E. Balknap, Washington, 1874.

9. Report of the Results of the Survey for the purpose of determining the practicability of laying a Telegraphic Cable between the United States and the Hawaiian Islands, Washington, Government Printing Office, 1892.

10. The Exploration of the Gulf of Guinea, by J. Y. Buchanan (*Scot. Geogr. Mag.*, vol. iv. pp. 177 and 233, 1888).

11. Deep-sea Sounding: a Brief Account of the Work done by the U.S.S. "Enterprise" in Deep-sea Sounding during 1883–86, by Captain A. S. Barker, U.S.N., New York, 1892.

12. Journal of Hydrological Observations made by the Officers of the Corvette "Vitiaz" during a voyage of Circumnavigation, 1886–89, by Admiral S. Makaroff, Admiralty, St Petersburg. (The proof sheets of the forthcoming volume of the Cruise of the "Vitiaz" have been kindly forwarded by Admiral Makaroff with permission to use the observations in this investigation).

13. Berichte der Commission für Erforschung des östlichen Mittelmeeres, Zweite Reihe (*Denkschr. d. K. Akad. Wiss. Wien*, Bd. lx.).

Lieutenant Baillie, Marine Superintendent of the Meteorological Office, obligingly re-drew for me a map, which he had prepared for Longman's New Atlas, 1889, showing the mean annual temperature of the surface of the ocean. This map I have revised and amplified from observations, in which mean annual values are given, or data from which they can be calculated, published by the Meteorological Council of London, the Scottish Meteorological Society, and the German, Norwegian, Danish and Dutch Meteorological Institutes. The parts of the ocean thus dealt with are the Gulf of Mexico, the Atlantic from lat. 20° N. to 5° S., round the south of Greenland, round Iceland, Norwegian Sea and Arctic Ocean, North Sea, Mediterranean, Red Sea, Persian Gulf, west of Arabian Sea, east of Africa from Cape Guardafui and round the Cape to near Whalfisch Bay, and south of Australia. Since this discussion deals with the temperature at depths where the influence of season is virtually not felt, it was absolutely essential that it should start from the mean annual temperature of the surface. It is evident that mean temperature for a single month, or groups of months that do not represent an annual mean, would simply mislead.

The *specific gravities* are those observed by the Challenger, reduced by Mr Buchanan, and published in the Challenger Reports,[1] together with the specific gravities given in the publications enumerated above as the sources from which the sea temperatures were obtained. The specific gravities given in the account of the Cruise of the "Novara" (Wien, 1862–65) have also been utilised, and also those given in the following publications of the Meteorological Council of London: Charts of Meteorological Data for Square 3, lat. 0°–10° N., long. 20°–30° W.; Charts of Meteorological Data for Nine Ten-Degree Squares, lat. 20° N. to 10° S., long. 10° to 40° W.; Meteorological Charts for the Ocean District adjacent to the Cape of Good Hope; and Twelfth Number of Meteorological Papers, published by authority of the Board of Trade. Professor Copeland has favoured me with a valuable unpublished series of specific gravities observed by him in the South Atlantic, west of Cape Colony, and thence round the Cape and through the Indian Ocean to a point a little to the south of Mauritius. When these observations of specific gravities had been entered in their respective positions on the maps, large sections of the ocean were found to be altogether unrepresented. These blanks, however, have been very largely filled up through the courtesy of the Meteorological Council in placing at my service their rich storehouse of observations not yet published. With these data the specific gravity of the surface of the oceans is fairly well represented.

14. Exploration of the Faroe Channel during the summer of 1880, in H.M.'s hired ship "Knight Errant," by Staff-Commander Tizard, R.N., and John Murray (*Proc. Roy. Soc. Edin.*, vol. xi. p. 63).

15. Deep-Sea Exploration in Faroe Channel by H.M.S. "Triton" in 1882, commanded by Staff-Commander Tizard, R.N. (Admiralty Blue Book).

[1] Report on the Specific Gravity of Samples of Ocean Water, observed on board H.M.S. Challenger during the years 1873–76, by J. Y. Buchanan, M.A., F.R.S.E. (Phys. Chem. Chall. Exp., pt. ii., 1883).

As regards the depths of the sea dealt with in this Report, the observations were entered in their places on the separate maps ; but it is right to state that at none of these depths, not even the 100 fathoms depth, are the observations sufficiently numerous to warrant the drawing of lines of equal specific gravity, except for comparatively restricted areas of any of the oceans. The standard temperature of 60° Fahr. adopted by Mr Buchanan in his Report has been employed, the standard density being that of distilled water at 39°·2 (4° C.). In all cases where the specific gravities have been published in accordance with other standards, they have been reduced to the above standard. The specific gravities taken from the publications of the Meteorological Council are all average specific gravities, many of them being the means of numerous observations, and on this account they are the best data at present available. By help of the numerous specific gravities observed by Admiral Makaroff in his cruise, and published *in extenso* by him, good averages were also obtained for portions of the route traversed by the "Vitiaz."

The influence of the protracted rainfall of the summer monsoon on the one hand, and virtually rainless weather tracks on the other, strongly impress their specific gravities over wide regions. The whole of the sea off Southern Asia, from Ceylon round to the Chinese Sea and northwards, during the summer months indicate specific gravities much lower than occur anywhere else on the globe in similar latitudes, being occasioned chiefly by the heavy rains of the summer monsoon on the coasts.

On the other hand, all the data entered on the maps for depths of 100 fathoms and greater depths were simply single observations of specific gravity, and the same remark applies to the temperatures employed in constructing the maps. Specific gravities thus obtained, as well as single temperatures from the same depths, may be truly regarded as good annual means.

There were really no correct observations of deep-sea temperatures till the Miller-Casella thermometer, and similar thermometers having their bulbs protected from outside pressure, came to be employed. For some time it was concluded that, even with bulbs so protected, it was necessary to reduce the observed readings, the rate proposed by Captain Davis being 0°·5 Fahr. for every mile of descent from the surface ; and in accordance therewith the whole of the temperatures published in the seven Preliminary Reports of Ocean Soundings and Temperatures obtained by H.M.S. Challenger, 1873-76, were corrected.

After the return of the Challenger the thermometers used during the Expedition were handed over to Professor Tait, with a view to "the reduction of the deep-sea observations which were made on board the Challenger, in so far as these are affected by pressure." The investigation, with the results, is published in the Challenger Reports.[1]

[1] Report on the Pressure Errors of the Challenger Thermometers, by Professor P. G. Tait (Narr. Chall. Exp., vol. ii., Appendix A, 1882).

A summary of the results is given in that paper at page 42, where it is shown that at a depth of 2500 fathoms, or nearly 3 miles, the mean correction of all the thermometers examined is only 0°·27 Fahr., the largest correction of any one of these thermometers being 0°·41 Fahr.

The observations of deep-sea temperatures strictly as observed, no correction being thus shown to be needed, are published in the Challenger Reports, together with the same temperatures represented by curves on 258 plates.[1] The curves are drawn, *libera manu*, through the observations, which are fully detailed at the top of each plate, allowance being thus made for such errors of observation as 10°, 5°, 1°, &c. The figures adopted in constructing the accompanying maps of deep-sea temperature are taken directly from the curves. In dealing with the other observations employed in this discussion, the observations as read are alone employed, any correction for pressure on the bulbs of the thermometers being in no case allowed for. As regards the important series of observations made by Commander Belknap, U.S.S. "Tuscarora," it is stated in his Report, p. 18, what corrections were applied to the thermometers for depths of 100, 300, 500, and 700 fathoms, but no further explanation is given. An examination, however, of the observations themselves at all depths as printed makes it sufficiently plain that Captain Davis' correction of half a degree Fahr. for each mile of depth had been applied throughout. Before, therefore, entering the temperature observations of the "Tuscarora" on the maps, they were *increased* by the amount by which they had manifestly been diminished, before publication, by the application of Captain Davis' rule. It was interesting to note that when the "Tuscarora's" course was in the vicinity of the course of the Challenger, "Egeria," &c., the additions made to the published readings brought them into accordance with the readings of these other ships.

As this discussion deals only with depths at which the temperature is virtually uninfluenced by season, no depths less than 100 fathoms are examined. The temperature maps which accompany this Report are for depths of 100 fathoms, and then, in succession, for each additional 100 fathoms down to 1000, then for 1500, for 2200 fathoms and another for bottom temperatures. It is plain that in this discussion no temperatures of the surface of the sea are admissible except good mean annual temperatures of the surface, it being these and these alone that rule deep-sea temperatures. Hence it is impossible to overestimate the value of Lieut. Baillie's map showing the mean annual distribution of the temperature of the surface.

In order to arrive at a correct knowledge of the mean temperature of the ocean considered as a whole at each of the depths selected, all the temperatures at each depth were averaged, excluding the temperatures which are from so-called "closed areas." The mean temperature thus arrived at is entered on each map, and in drawing the isothermal lines, all temperatures above this mean are represented by red lines, and

[1] See *Ante*, No. 1, footnote, p. 3.

temperatures below it by black lines. These lines thus show graphically for each depth the regions where the temperature is above the average for that depth and where it is below it.

The most striking fact revealed by deep-sea observations of temperature is the very low temperature of the ocean at great depths in all latitudes, this being but a little way above the freezing-point of fresh water. To show this feature more exactly, a map was constructed indicating the temperature at the depth of 2200 fathoms. The average of all the observations made at this depth give a mean temperature of 35°·2. Another map has been constructed (Map 14) on which are entered the differences of the individual temperatures from this average, those which exceed it being entered in red ink, and those under it in blue ink. The result is interesting and instructive.

Everywhere over the Indian Ocean temperatures at 2200 fathoms are under the mean. There are twenty observations whose mean temperature is 34°·4, being thus 0°·8 lower than the general ocean at this depth. Over the whole of the South Atlantic to the south of lat. 10° S. temperatures are also under the mean, slightly in the eastern side of the ocean but very largely in the south-west of it. At three stations to the east of Buenos Ayres between longitudes 35° and 45° west the temperature is only 32°·6, which is the lowest yet observed in any part of the ocean not within a " closed area " ; that is, in a position shut off by submarine ridges from the general oceanic circulation. It is highly probable that temperatures even lower may yet be observed off Cape St. Roque, where 32°·2 has been observed at a depth of 2537 fathoms. Temperature is also under the mean over the whole of the Pacific Ocean, except (1) to westwards of a line drawn from the south and west of Japan to the north of New Zealand ; and (2) over a large section of that ocean enclosed within a line passing from Valparaiso and curving round by about Marquesas Islands to Acapulco, though it must here be stated that observations are wanting from Valparaiso to Galapagos in and over the central parts of this region. Future soundings will probably show that these are areas shut off by a low enclosing ridge at the bottom. The lowest temperature in the Pacific is 33°·2, or 2°·0 under the mean, a little to the south of Kamtschatka. Temperatures nearly a degree under the mean have been observed off Alaska, San Francisco, to the north-east of New Zealand, and in about lat. 40° S. and long. 107° W. But throughout the cold area of the Pacific generally the deficiency below the mean temperature of the oceans is extremely small. Thus, leaving out the small areas where temperature is nearly a degree under the mean, the mean temperature of the remaining sixty-three stations is 35°·0, or only 0°·2 under the mean temperature of the whole ocean at that depth. Speaking generally, the temperature of the Pacific at 2200 fathoms closely approximates to the average of the ocean taken as a whole at this depth.

The temperature of the North Atlantic is everywhere above the average of the whole ocean, and the amounts of excess are for the great depths in all cases large. In

this ocean, temperatures have been observed at fifty-five stations, the mean of these being 36°·4, or 1°·2 above the average, thus showing a strikingly marked difference between the deep-sea temperature of the Indian Ocean and the South Atlantic on the one hand, and the North Atlantic on the other. The two sections of the Pacific Ocean where the temperature is above the average do not show any such excess as appears in the North Atlantic, the excess above the average being, roughly speaking, about half a degree. The mean of the two stations in the China Sea is 36°·5, or 1°·3 above the average.

In connection with deep-sea temperatures the following facts are interesting. In the Arctic Ocean, at a depth of 2005 fathoms, Professor Mohn observed a temperature of 29°·6 in lat. 68° 21′ N. and long. 2° 5′ W. This position, however, is in a "closed area," shut off from the general oceanic circulation by the Wyville-Thomson Ridge. A little to the south of Greenland, at 1860 fathoms, 33°·4 has been observed; and ten degrees to westwards, at 1750 fathoms, 34°·0. To the east of Ceylon, at 2020 fathoms, 33°·9 was observed, lat. 9° N. and long. 85° E., and to north-west of Madagascar, at 1877 fathoms, a temperature of 33°·5 has been noted. On the other hand, to the east of Australia, lat. 19° S. and long. 165° E., at a depth of 2525 fathoms, the temperature was found to be 36°·4. It will be seen, when the bottom temperatures are dealt with, that the Atlantic stands alone among the oceans for relatively high temperatures at great depths.

It is remarkable that at the depth of 2200 fathoms the water of the sea falls to its lowest temperature off the east of the Argentine Coast of South America, and is nearly, if not quite, at its highest off the east coast of North America, thus pointing to very diverse conditions in the oceanic circulation off the east coasts of these two continents.

The striking fact is that deep-sea temperatures in all latitudes, equatorial as well as polar, are uniformly low, and, except in a few restricted regions, do not differ from each other more than about two degrees. The exceptional regions are where the Sea of Okhotsk meets the ocean; the whole of the deep water immediately to the east of South America from Cape St Roque to Grahame's Land, in Antarctica; and, in a less degree, the southern portion of the Indian Ocean. It is also to be noted that the lowest deep-sea temperatures are found in those parts of the ocean which lie in the Southern hemisphere, and that, on the whole, higher temperatures are encountered as we recede from the Antarctic region. It may also be pointed out that the lower deep-sea temperatures extend farther to the north from the Southern Ocean, just over those depths of the sea which appear to have, and probably do have, a direct communication with the south; that is, are not cut off by any intervening submarine ridge separating them from the cold waters of Antarctica.

There can be no doubt that these very low deep-sea temperatures have their origin in the Southern or Antarctic Ocean, the icy-cold waters of which are propagated north-

wards, the rate of propagation being so slight as to be regarded rather as a slow creep than as a distinctly recognisable movement of the water. It is evident that the increase of temperature from the bottom of the ocean to the surface is due to the slow descent of the warmer water of the surface carrying downwards their higher temperature to greater depths.

The following mean temperatures, calculated from the whole of the observations in all latitudes for the different depths, show the rate of diminution of the temperature downwards :—

Depth in Fathoms.	Temperature.	Depth in Fathoms.	Temperature.
100	60°·7	900	36°·8
200	50°·1	1000	36°·5
300	44°·7	1100	36°·1
400	41°·8	1200	35°·8
500	40°·1	1300	35°·6
600	39°·0	1400	35°·4
700	38°·1	1500	35°·3
800	37°·3	2200	35°·2

Thus the fall of temperature from 100 fathoms to 2200 fathoms is 25°·5, and of this there is a fall of 10°·6 from 100 to 200 fathoms. For each successive 100 fathoms the falls of temperature are 5°·4, 2°·9, 1°·7, 1°·1, 0°·9, 0°·8, 0°·5, 0°·3, 0°·4, 0°·3, 0°·2, 0°·2, and 0°·1, and for the 700 fathoms from 1500 to 2200 fathoms the mean fall is only the tenth of a degree.

Prevailing Winds over the Ocean.

These will be best studied in detail by referring to the Report on Atmospheric Circulation, pp. 48–69, and the maps 27–52, which show the isobaric lines and prevailing winds of the globe for the months and the year. In these maps the general movement of the atmosphere over the different oceans through the months of the year is clearly shown. The outstanding features of the circulation of the atmosphere bearing on this discussion will be seen in an examination of the prevailing winds in January and July.

January.—In the North Atlantic, north of about lat. 35° N, atmospheric circulation is ruled by the low pressure about Iceland, in conjunction with the high pressure over North America on the one hand and Eurasia on the other. From this geographical distribution of the mass of the earth's atmosphere, it inevitably follows that over the east coast of America the prevailing winds are north-westerly, and over Western Europe south-westerly. Hence the prevailing winds at this season blow the surface waters of

the ocean from the American coast and West Indies across the Atlantic, then northwards over its eastern side, and thereafter round the north of Norway and along the north of Siberia. This state of things results, as regards Europe, in the setting-in of a strong ocean current bringing the waters of warmer latitudes to its western shores, and on the other hand, as regards America, the draining away from its shores of its warmer surface waters, and as this water is replaced by the upwelling of the water from greater depths, it is therefore of a lower temperature than that removed by the surface current.

Similarly, the wind system of the North Pacific is ruled by the low pressure in the north of that ocean, resulting in north-westerly winds in the east of Asia and south-westerly and southerly winds in the west of North America. The great dryness and low temperature of these north-westerly winds have the effect of lowering to a still greater degree the temperature of the North Pacific Ocean.

In the southern hemisphere, south of lat. 35° S., there occurs no circumscribed region of low pressure, but a broad ring, in width about 30° of latitude, of very low pressure, passes completely round the globe, falling to a mean pressure of about 29·000 inches near lat. 63° S. Over this broad space of low pressure the prevailing winds are strong, and approximately west or north-westerly all the year round. These strong north-westers pour south into the Southern Ocean, by the surface currents they generate and maintain, inconceivably enormous volumes of water from lower latitudes, and these waters, be it noted, of a comparatively high temperature and specific gravity. These warm and specifically heavy waters in their passage southward by and by necessarily sink to greater depths, and are overlaid by the cold and specifically light waters from the melted snow and icebergs of the Antarctic region, as suggested by Dr Murray.[1] A striking feature of the waters of the Southern Ocean is the interdigitation of currents differing very widely from each other both in temperature and specific gravity, the colder of these currents having their origin, doubtless, in the numerous icebergs of these regions. An important part played by these vast currents of warm and specifically heavy water is to mitigate, most materially, the cold of the Antarctic region, particularly at great depths, and thus restrict the ice-clad area to its present limits.

At this season, south of the equator, systems of low atmospheric pressure are not situated over the ocean but over the land. Of these systems there are three,—in South America, South Africa, and Australia. The most pronounced of these is in Australia, and the result is that, on all coasts, winds blow from the sea upon the land, and at the same time the surface currents of the ocean are directed towards the land.

July.—In this season the geographical distribution of pressure is exactly the reverse in Australia of what obtains in January. Everywhere it increases on advancing from the coast into inland regions. The lowest pressure, about 30·000 inches, occurs near

[1] The Renewal of Antarctic Exploration, by John Murray, Ph.D., LL.D., of the Challenger Expedition (*Geogr. Journ.*, vol. iii. p. 18, 1894).

the north coast, and the highest, 30·180 inches, over the basin of the Murray River and its affluents. From this region the diminution in pressure is uninterrupted to the north, even as far as the low-pressure system of Central Asia. Hence, the prevailing winds of Australia are essentially an outflow from the high pressure of the interior towards the lower pressure of the coasts, particularly the north coast, and these winds are S.E. on the north coast, S.W. at Brisbane, W.N.W. at Sydney, N. at Melbourne, and N.E. at Adelaide. The high pressure of the south of Australia is continued westwards in the same latitudes through the Indian Ocean. From these latitudes (about lat. 30° S.), pressure falls continuously northward to the low pressure of Central Asia, and, following inevitably that diminution of pressure, southerly winds sweep across that ocean home into Asia. Where they touch the coast after traversing a great extent of the ocean, such as the coasts of the Bay of Bengal, they bring with them a heavy rainfall, which, from the lowering of the specific gravity thus occasioned, has an important retarding effect on the vertical circulation of the ocean there. On the other hand, on the northern and western parts of the Arabian Sea, the rainfall is exceedingly small, as the winds there have traversed but a small breadth of the ocean, and consequently, from the dryness of these winds, the specific gravity is much increased, and the vertical circulation becomes thereby accelerated.

Similarly, as pressure diminishes from about lat. 25° S. in the Pacific uninterruptedly to the low pressure of Central Asia, the southerly winds on the south-eastern coasts of Asia, after having traversed a wide extent of ocean, pour a heavy rainfall on these coasts and outlying islands, thus lowering greatly the specific gravity of the surface during the warm months.

The winds of Europe are determined by the high pressure of the Atlantic in its relations to the low-pressure systems of Asia and Africa at this time. On the coasts of Spain and North-West Africa the prevailing winds are northerly ; farther to the north, on the coasts of France and the British Islands, south-westerly ; and on the coast of Norway westerly and north-westerly. The curving of the winds round the anti-cyclone of the North Atlantic, from the N.E. off the coast of Africa, to E. and S.E. in the region of the West Indies, to S. and finally S.W. off the Eastern States of America, has all-important bearings on the circulation of the waters of that ocean.

The centre of lowest pressure in North America is over the States about Utah, from which pressure rises all round, but chiefly to the south-east and west. In accordance with this arrangement of the pressure, the winds blow from the Gulf of Mexico home to the coasts of the States as southerly winds. On the other hand, the winds on the coasts of the Pacific States are N. and N.W. as far north as Vancouver, but over that island, and along the coasts to northward, they are S.W.

From lat. 30° S. to lat. 63° S. pressure, as already explained, diminishes uninterruptedly from 30·150 inches to 29·000 inches, over a broad ring going round the

whole globe during all seasons of the year. Over the whole of this vast space westerly and north-westerly winds sweep as strong winds, subject to little, if any, variation with season. From the enormous quantities of warm waters they impel before them into the Southern Ocean, they may be regarded as playing the most conspicuous part, of all the prevailing winds, in the circulation of the waters of the ocean.

Specific Gravity of the Ocean. (Map 1.)

Of all oceans the South Atlantic is the one containing fewest islands, and it is traversed by virtually the same winds at all seasons of the year. In that ocean, accordingly, the distribution of the specific gravity of the surface is presented in its simplest form. From the equator to the estuary of the Rio de la Plata the prevailing winds are south-easterly trades. It is also to be noted that these winds blow from higher to lower altitudes, and consequently from regions of lower to regions of higher temperatures (see Map 2). From these conditions result a drier atmosphere, increased evaporation from the surface of the sea, and a small rainfall, much smaller than would otherwise be, owing to the almost total absence of islands which would, in proportion to their height, condense the aqueous vapour into rain, and thus lower the specific gravity in this ocean. Hence, the specific gravity increases on nearing the South American coast, attaining the maximum, 1·0275 to 1·0278, from Bahia to Rio de Janeiro. Off the west coast of Africa, in the same latitudes, specific gravity is much lower, even though that coast, from lat. 10° to 30° S., is one of the driest regions of the globe, much drier, indeed, than the corresponding coast of Brazil. This is due to the fact that the prevailing westerly winds on that coast are but the in-draught from the sea towards the heated land of Africa, and, necessarily, owing to the distribution of pressure, they extend only a short distance westwards into the Atlantic. Further, as the whole wind-system, together with the surface currents of this portion of the South Atlantic, is drifted westward by the south-east trades, there is an upwelling along the more easterly portion of the ocean to make good the surface drain, and the specific gravity of this deep water brought to the surface is much lower than that of the surface waters to the westward owing to the large evaporation of this region, to which these surface waters are subjected during their long course over this ocean.

On the other hand, the North Atlantic presents features strikingly different. For a considerable portion of the year northerly and north-westerly winds set in on the north-west coast of Africa, and, since they have traversed a considerable extent of the Atlantic, and have been steadily advancing into warmer latitudes, that region is characterised by a specific gravity higher than anything observed off the coast of South Africa. Again, the north-east trades do not blow home on the shores of the Eastern States of America. On the contrary, the north-east winds from the anticyclone of the North Atlantic curve

round to east, south, and, finally, to the south-west as they sweep over the West Indian Islands and past the east coasts of the States. The result is that a generous rainfall is deposited over the Eastern States, and on the western portion of the Atlantic adjoining. Thus, the specific gravity there is reduced, and it is still further reduced by the upwelling set in along that coast by the south-westerly winds blowing seawards from the land.

These south-westerly winds pass northwards over the Atlantic, more particularly its eastern half, at all seasons, carrying with them their higher temperature and specific gravity. This is seen in the most impressive manner by the extraordinary protrusion northwards of the specific gravity line of 1·0260 which reaches the latitude of about 72° N. In the North Pacific the northern extension of this line stops at lat. 34° N., or nearly 40° short of its position in the Atlantic.

In the closed basin of the Gulf of Mexico, which is virtually cut off from the great wind system of the North Atlantic, the specific gravity of its eastern half is 1·0271. Again, in the closed area of the Mediterranean the specific gravity rises to 1·0280 in the western basin, and to 1·0290 in the eastern basin. Further, in the Red Sea, which is more effectually closed to the ocean than either of the above seas, the specific gravity rises from 1·0275 at the Straits of Bab-el-Mandeb successively to 1·0310 near Suez, being the highest known mean specific gravity anywhere observed on the surface of the sea.

Of all the great oceans, the North Pacific shows by far the lowest specific gravity on the surface. The two regions of highest specific gravity, and they are comparatively of small extent, are marked off by the line of 1·0265. During the whole year, but especially the summer months, the rainfall over the western half of this great ocean is large, being occasioned both by the many high islands that the prevailing winds meet in their course, and by the low barometric gradients characterising this region, resulting in calms and light winds, to which this ocean owes its name, and a larger rainfall and less evaporation than would otherwise be observed. Further, as this ocean on its northern side is really a closed basin, neither the prevailing winds nor the ocean currents they generate cross into the Arctic Ocean, but re-curve round on the coast of America from lat. 50° N. southward. Hence over the whole of that part of the North Pacific skies are more clouded, rainfall larger, and evaporation and specific gravity therefore less.

In the South Pacific the area of high specific gravity is large, extending from South America across the whole breadth of the ocean. The region of highest specific gravity, 1·0270, is confined to the eastern half of the ocean, the specific gravity of the western half being reduced from like causes to those which lower the specific gravity of the western half of the North Pacific.

The Indian Ocean exhibits several marked peculiarities of its own. Owing to the arid climates of Arabia and adjoining regions, and the high specific gravity of the Red

Sea, the specific gravity of the Arabian Sea is high, but everywhere else to the north of lat. 10° S. it is rather low, owing no doubt to the large and, over wide areas, heavy rainfall occurring there. For a considerable portion of the year the prevailing winds of West and North Australia are from the sea, where barometric pressure is much higher than in the interior of the continent, and consequently the specific gravity is higher for some distance round these coasts. Similarly, over the western half of this ocean the prevailing winds blow home on the coast of Southern Africa, in the interior of which in the same months pressure is also low, and, just as happens off South America, the specific gravity is largest on the coast to the south of the latitude of Madagascar, which lies quite open to the ocean. The deflection of the lines round the South African coast is very interesting in connection with the well-known warm and cold ocean currents which are so striking a feature of that part of the globe. Fortunately, these lines are drawn from good annual mean specific gravities, calculated from numerous observations made during each of the twelve months of the year, which have been published by the Meteorological Council. It will be observed that the highest specific gravities of the Indian Ocean are found in the region of the anticyclones of that ocean, just as occurs with respect to the other oceans, particularly the Pacific Ocean.

The lower specific gravities observed in central Atlantic, between the higher specific gravities of the North and South Atlantic, are also annual averages, based on numerous observations, and mark with great distinctness the region between the two trade winds. It will be observed that in this region from long. 30° W. the specific gravity constantly diminishes eastward to the head of the Gulf of Guinea, where it falls below 1·0260, being lower than occurs anywhere on the coasts from the English Channel to the Cape of Good Hope.

The region of lowest specific gravity anywhere hitherto observed is the southern part of the Sea of Okhotsk where the mean falls to 1·0240, as calculated from numerous observations made there by Admiral Makaroff on board the "Vitiaz," and the next lowest between Greenland and Spitzbergen, where Professor Mohn, also from numerous observations, gives the low mean specific gravity of 1·0245. The mean of the ten observations made by the Challenger to the south of lat. 60° S. is 1·0247, and of the six of these made near to or to the south of the line of 1·0245 on Map 1, the mean is 1·0245, being the same as Mohn's line of least mean specific gravity. The low specific gravities round the southern part of South America are occasioned, on the west coast chiefly, by the heavy rainfall of that region, and on the east coast, in addition to the rainfall, by the upwelling there resulting from the strong westerly winds blowing from the land seawards.

Mean Annual Temperature of the Surface of the Ocean. (Map 2.)

In this map, showing the mean annual temperature of the surface of the ocean, the deeper red shaded portions indicate those regions where the temperature is highest, or where it exceeds 80°.

The area of high temperature does not quite circle the equatorial region of the globe, as it does not occur in the Pacific from long. 117° to 140° W. In the Atlantic and eastern portion of the Pacific, these areas of high temperature lie north of the equator, which is due to the circumstance that in these parts of the ocean the south-east trades protrude north of the equator, being the simple result of the geographical distribution of atmospheric pressure there. Quite different is it in the western division of the Pacific where this area of high surface temperature extends east of Australia as far south as lat. 20° S. This striking extension southward of the temperature is occasioned by the circumstance that, for eight months of the year, the line of lowest barometric pressure is there to the south of the equator, and, necessarily, accompanied by northerly winds, which propel into more southern regions the warmer waters of the surface. The point here insisted on is vital to the whole question of oceanic circulation.

Another important result of the geographical distribution of atmospheric pressure in the Atlantic and Pacific is that in the Atlantic the north and south trades are stronger and more persistent than those of the Pacific, and the inter-space between them characterised by calms and very light variable winds is therefore much narrower in the Atlantic than in the Pacific. From this it follows that the region of highest surface temperature in the Atlantic is comparatively much contracted in width, whereas in the Pacific it occupies a breadth nearly four times greater.

To the north of lat. 13° S. the area of maximum surface temperature overspreads the whole of the Indian Ocean, including the Arabian Sea and the Bay of Bengal, except the north-western portion of the Arabian Sea. This comparatively low temperature over the western division of the Arabian Sea is brought about by the prevailing north-westerly winds there in the summer and also the winter months, which drive the warm surface water to the south-eastwards, and thus bring, by upwelling, the colder waters of lower depths to the surface. The effect is well seen in the mean monthly temperature of the surface of the sea off the Arabian coast about long. 57° E., which, during the spring months, is 82°·8, but falls in the summer months to 76°·3 when the N.W. winds are strongest, rising again in the autumn to 79°·4. This low summer temperature is the more remarkable since the north-west winds which then prevail come from the deserts of Arabia, and are therefore hot, dry and rainless till they have traversed the sea a considerable way to the south-east. On the other hand, the prevailing winds at this season at the head of the Bay of Bengal are southerly and

south-easterly. They therefore blow home on that coast, bringing from tropical regions the warm waters of the surface over the whole of the northern portion of this sea.

On the western part of the North Atlantic the isothermal of 75° is carried to a higher latitude than anywhere else in the ocean, owing to the prevailing southerly and south-westerly winds, which carry thither the high temperature waters immediately to the south. On the other hand, the isothermal of 45° is carried to a lower latitude near Nova Scotia than anywhere else in the ocean, owing to the prevailing north-westerly winds there in the cold months of the year, and the cold currents that later on descend on these coasts from the Arctic regions. The isothermal of 45° is further remarkable in that it extends over a far larger number of degrees of latitude than any other isothermal, viz., from lat. 45° to 68° N., or twenty-three degrees of latitude.

A marked feature of the distribution of the temperature of the North Atlantic is the crowding of the isothermals off the coast of America, and their opening out into higher latitudes as they approach Europe and to lower latitudes as they near Africa. Thus on the American coasts the isothermals from 45° to 75° extend over twelve degrees of latitude, but on the eastern side of the Atlantic to forty-eight degrees. An important point is that the highest temperature as regards latitude is not near the coast, but in the ocean a considerable distance to westwards. The lowering of the temperature off the north-west of Africa deserves attention, as being the direct result of the curving round of the prevailing winds in this part of the North Atlantic anticyclone to north-west and north, thus transferring the surface waters from higher to lower latitudes. A similar effect is even more emphatically expressed in the isothermals of the air in this part of the ocean (see Map 13 in the Report on Atmospheric Circulation). A similar lowering of the temperature, from similar causes, is seen off the west coasts of all the continents, the prevailing winds in these regions passing from higher to lower latitudes. On the other hand, as the prevailing winds on the western sides of the oceans pass from lower into higher latitudes, temperatures there are higher, except in the higher latitudes, where icebergs and icefloes, polar currents, and upwelling occur.

The warm currents to the east of South Africa, and the cold currents to the west, are well shown on Map 2, on which the results are now stated with great accuracy of detail from the Meteorological Charts for the Ocean District adjacent to the Cape of Good Hope, issued by the Meteorological Council.

The lowest isothermal on the map is 30° in the Arctic Regions. The isothermals here, to the north of the British Islands, are taken from Professor Mohn's great work on The Meteorology of the Norwegian North Atlantic Expedition, 1876–78 (Plate XVI.). These mean annual temperatures of the Norwegian Sea and Arctic Ocean, so carefully prepared by Mohn, are of first importance in their bearings on ocean circulation, and the same remark may be extended to the deep-sea temperatures of the same expedition.

Thus, the most powerful causes concerned in deflecting the isothermals of temperature of sea-water and the lines of specific gravity from their normal east and west directions are the prevailing winds and the surface currents of the ocean they originate and maintain; and further, as regards the specific gravities, the rainfall of the different regions powerfully influences the direction of the lines, and, as will appear further on, the vertical and horizontal movements in the ocean to which they give rise.

Temperature of the Ocean at Different Depths.

The Atlantic and Pacific Oceans.

Depth of 100 *Fathoms* (Map 3[1]).—On this map the isothermals are drawn for every five degrees of temperature, except in the cases of the highest and lowest temperatures of the oceans respectively, which are given to the nearest degree. From all the observations the mean temperature at this depth is 60°·7, and on the map, as on all the others, isothermals above the mean temperature at the particular depth are coloured red, and below it are coloured blue.

Looking first at the distribution of the temperature from about lat. 30° N. to lat. 30° S., it is at once seen that the higher temperatures lie to the westwards of the anticyclonic regions of the different oceans, and that the temperature of the western portions of these oceans is very much higher than in the eastern portions. The great difference observed is occasioned by the ocean currents setting in to the west, which are originated and maintained by the north-east and south-east trade winds. These winds drive the warm surface waters before them onwards towards the eastern coasts of the continents. In those cases where the higher temperatures do not quite reach the continents, it is owing to the interposition of islands in their paths; as, for example, Madagascar, the West Indies, and the East Indies, as respectively affecting Africa, North America, and Asia.

The North and South Atlantic present a strong contrast to each other. It will be seen that on the whole the surface specific gravities of the two oceans (Map 1) do not very materially differ from each other, but their temperatures at the 100 fathom depth are widely different. In the South Atlantic the area showing a temperature above 60°·7, the mean temperature of the oceans, is small as compared with the extent of the same temperature and upwards in the North Atlantic. Further, in the South Atlantic the highest isothermal is only 63°, whereas in the North Atlantic there is a large area with a temperature exceeding 65°, which encloses two small areas each with a temperature rising to 70°.

[1] A large number of maps were constructed for depths intermediate to those discussed in this Report, particularly for depths down to 200 fathoms, in connection with the question as to the depth to which the influence of season is experienced.

It has been long recognised that in the Atlantic the region of calms between the north and south trades is in all seasons north of the equator, reaching its northern limit, lat. 13° N., in July, and its southern limit, lat. 2° N., in January. Hence, in all seasons the south-east trades penetrate into the northern hemisphere, driving before them the warm surface waters of the South Atlantic. Thus vast quantities of the heated surface water of the South Atlantic are transferred bodily to the North Atlantic, resulting in these oceans presenting, as regards their temperature, the strongest contrasts to each other at all depths down to the bottom of the sea. The mean annual position of this region of calms may be shown by drawing on Map 51 of the Report on Atmospheric Circulation a line across the Atlantic, marking out the path of least barometric pressure of that region. Now it is this simple circumstance, the position of this line, which gives to the North and the South Atlantic Oceans their distinct contrasted features.

Turning now to the Pacific Ocean on the same map, we find that the line of least barometric pressure lies not north, but south, of the equator, from long. 160° E. to long. 130° W. An examination of the maps for the separate months shows that for eight months of the year this state of things substantially holds good, culminating in December, January, and February when barometric pressure is very low in Australia. In these months the north-east trades and ocean currents of the Western Pacific extend into the South Pacific to about lat. 15° S., as shown by the current charts now in course of preparation by the Meteorological Council.

The isothermals for the depth of 100 fathoms (Map 3) show that the manner of the distribution of the temperature in the North and South Pacific is precisely the reverse of what obtains in the Atlantic. In the North Pacific the highest temperature, 70°, is restricted to two very small areas, whereas in the South Pacific the area marked out by the isothermal of 70° covers a very extensive region, and encloses another region, also very extensive, where the temperature exceeds 72°. In truth at this depth the South Pacific presents a region with a temperature above the general mean of the ocean, larger than the high temperature regions of all the other oceans combined. The *rôle* played by Australia, the low atmospheric pressure of its warmer months mainly bringing about the result, deserves careful consideration.

A featuré of the temperature in all the oceans is a pronounced increase in the eastern equatorial region of each ocean on nearing the continents. Thus in the Pacific about the Galapagos Islands, temperature is 62°, or 12° higher than in the same latitudes some distance to westward; in the Atlantic it rises to 59° in the Gulf of Guinea, or 6° warmer than it is to westward; and in the Indian Ocean it rises to 60°, or 4° higher than it is to westward. This peculiarity arises from two causes, one being the monsoonal deflection of the trade winds, for some distance out to sea, out of their course to westward, so as to blow towards and in upon the heated land of the continents; and this

cause operates strongest during those months when, as in the case of Australia, atmospheric pressure is lower in the interior than on the coast. Those winds, of course, blow the warm waters toward the coast. The other cause is the back water, or counter equatorial current to the east, which sets in particularly in the eastern division of the region of calms between the north and south trades.

In the Pacific, in equatorial regions, a great breadth of that ocean from Galapagos Islands to long. 165° E. has a temperature under the mean, falling to 50° in the middle region from long. 122° to 148° W. This low temperature of 50°, taken in connection with the isothermal of 72°, only eighteen degrees of latitude to the south, presents what may be regarded as perhaps the most striking fact of oceanic circulation. In August 1875 the Challenger took several soundings in this part of the ocean, and in Number 6 of the Preliminary Reports there is represented on Plate IV. the vertical distribution of temperature in this region as contrasted with surrounding regions. The following extracts from the Challenger soundings, Nos. 410 and 417, taken respectively on August 30 and September 14, 1875, will show the extraordinary differences in the rates of change of temperature with depth in these two parts of the ocean down to 200 fathoms :—

Depth in Fathoms.	No. 410. Lat. 7° 35′ N. Long. 149° 49′ W.	No. 417 Lat. 11° 20′ S. Long. 150° 30′ W.	Difference.
Surface.	81°·0	80°·0	+ 1°·0
10	79°·3	79°·9	– 0°·6
20	79°·3	79°·8	– 0°·5
30	79°·3	79°·6	– 0°·3
45	78°·2	79°·4	– 1°·2
50	74°·0	79°·0	– 5°·0
60	63°·4	78°·0	– 14°·6
70	56°·2	76°·7	– 20°·5
80	52°·6	75°·3	– 22°·7
90	51°·0	73°·7	– 22°·7
100	50°·3	72°·0	– 21°·7
110	50°·0	70°·1	– 20°·1
120	49°·8	68°·3	– 18°·5
130	49°·6	66°·2	– 16°·6
140	49°·4	64°·0	– 14°·6
150	49°·2	61°·4	– 12°·2
160	49°·0	58°·9	– 9°·9
170	48°·8	56°·4	– 7°·6
180	48°·6	54°·2	– 5°·6
190	48°·4	52°·4	– 4°·0
200	48°·2	50°·8	– 2°·6

These two examples may be regarded as typical of the distribution of the temperature over the greater portion of the intertropical part of the Pacific from the surface, where the differences are small, downwards to 100 fathoms depth, where the difference exceeds 20°. It is further seen that the difference nearly ceases at about 200 fathoms. Similar areas of low temperature are seen in the Atlantic to the west of Lower Guinea, and again in the Indian Ocean to the south of Ceylon. From their evident relations to the systems of atmospheric circulation, temperatures, and specific gravities of their respective oceans, a similar origin is suggested for them all.

These areas of low temperature occur to the north of the equator in the Pacific and Indian Oceans, but to the south of it in the Atlantic. Now these are the sides of the equator where are located at this depth areas of high temperature of less extent and intensity and of lower specific gravity than are found on the other side. In other words, they occur on the side of the equator where the warm waters of the surface, owing to the diminished specific gravity, are not diffused or conveyed so quickly downwards to greater depths.

Again, looking at the Pacific, the expanse of low temperature is bounded on each side by the trade winds, particularly by those tracks of the ocean where they are strongest. These trades impel to the westward warm surface currents, which by friction extend to a considerable depth in the ocean. To the eastwards these currents are fed by the current succeeding them generated by the trades, but on their equator side and the intervening space, the current, depth for depth, is more sluggish, because the surface winds there are either very light or wholly wanting. The result is that the currents of the trades proper take the largest source of their supply from the sea directly underlying the calm intervening region between the north and south trades. Hence there necessarily sets in an upwelling from lower depths to make good the drain, and the waters thus drawn from greater depths brings the low temperature of these depths up with them.

If this were all, these areas of low temperature would be found close up to the respective continents on the east side of the ocean. Now in no instance are they found in such a situation, but instead, some distance to westward in the ocean, apparently proportional to the breadth of the ocean, and having between them and the continent to the east a subsidiary area of high temperature. These small areas of high temperature have their explanation in the back water surface currents flowing eastward between the trades inforced by the westerly winds of a monsoonal character which are encountered for some distance out at sea before arriving at the western shores of the continents.

It is probable that the greater volume of, and distance traversed by, these currents in the broad Pacific as compared with other oceans directly result in a stronger and more widespread upwelling, accompanied with a correspondingly extensive diminution of temperature. Again, the South Atlantic pours vast volumes of its warm surface waters into the North Atlantic to join the westerly current already formed and flowing there, and this

united ocean stream drifts westwards past the West Indian Islands and thereafter joins the great Atlantic north-easterly current. In these circumstances, the source of supply to meet the drain caused by these west-going currents cannot be found in the North Atlantic off the coast of Africa, that part of the ocean being filled with a strong flowing current which is generated and maintained by the northerly and north-easterly winds prevailing there, but is to be sought for in the South Atlantic near the place where the northern section of the south-east trades are weakest. And there it is located with the upwelling and characteristic low temperature of 53° which accompanies it. It may be pointed out that, while the temperature of the Gulf of Guinea is greater than it is over the ocean to westward enclosed by the isothermal of 55°, it is to the east of the area of lowest temperature, 53°, that the highest temperature of 59° is found on the Guinea coast.

The lowest temperatures yet observed at the depth of 100 fathoms are 29°·0 by the Challenger in lat. 65° 42′ S. and long. 79° 49′ E; 29°·2 by the Dundee whaling vessels off Graham's Land; 29°·7 by the Norwegian Expedition in lat. 75° 16′ N. and long. 0° 54′ W.; and 29°·8 by Admiral Makaroff off Okhotsk—all, it will be observed, closely approximate to each other.

Specific Gravities at depth of 100 *Fathoms.*—In the Pacific Ocean, between lat. 40° N. and 40° S. and long. 150° E. to 130° W., the following are the results of the specific gravities :—

	North Pacific.	South Pacific.
Number of Observations, . .	23	22
Highest, ...	1·0260	1·0271
Lowest, ...	1·0253	1·0260
Mean, ...	1·0256	1·0264

thus showing a marked difference in the specific gravities of the ocean at this depth. Over the region of highest temperature, which is south of the equator, the specific gravities are all high, but over the North Pacific they are low. They are low also in the region of lowest temperature, 50°, being only 1·0257. It may be added that the same low specific gravity occurs in lat. 15° S. and long. 94° W., where, in respect of the south-east trades, upwelling is to be expected, but to the west of this point, where high temperatures rule, it rises to 1·0269. Hence the high specific gravities of the South Pacific convey down to this depth a temperature much greater than is done in the North Pacific, where the specific gravity is much less.

In the North Atlantic, from lat. 12° to 40° N. the mean of the fifteen specific gravities observed over the whole breadth of the ocean is 1·0270, the lowest being 1·0264 and the highest 1·0278. This part of the ocean is therefore remarkable for its high specific gravity, higher, indeed, than any other part of the ocean from which we have observations. In the South Atlantic, from Cape St. Roque to Monte Video to long. 30° W. on the east, there are eight observations, giving a mean specific gravity of 1·0268, which

also is high. In the same ocean, between lat. 10° to 40° S., and a little to the west of long. 10° W., the Challenger took eight observations, with a mean of 1·0264, which is still a high mean, but less than the mean of 1·0268 found to westward as we near South America. But within or close to the region where temperature falls to 53° the five specific gravities observed by the Challenger were 1·0261, 1·0262, 1·0260, 1·0260, and 1·0261, giving a mean of 1·0261, thus corroborating the view that the low temperature of 53° found here is brought, by upwelling, from greater depths.

Depth of 200 *Fathoms* (Map 4).—The mean temperature of the ocean at this depth is 50°·1, showing thus a fall of 10°·6 from the mean at 100 fathoms. The part of the North Atlantic where temperature is above the mean, 50°·1, embraces now a very much wider area than that of the South Atlantic; further, within the same area the temperature rises much higher in the North than in the South Atlantic, the highest isothermal in the former being 64° whereas in the latter it is only 55°. In the North Atlantic the mean specific gravity is 1·0270 over the warm area, but over the similar area in the South Atlantic it is only 1·0261. Thus in the North Atlantic the specific gravity conditions favour a more rapid descent of the warmer surface water, which, as shown by the temperature observations, is what actually occurs.

In the South Pacific the warm regions embrace a much wider area than in the North Pacific, the temperature at 200 fathoms being still higher in that half of the ocean which receives the overflow of warm surface waters from the other half, precisely as obtains between the two divisions of the Atlantic. In the South Pacific the mean specific gravity is 1·0259, and of the North Pacific 1·0256, these, it is to be noted, being both very much less than the mean specific gravity of the North Atlantic, which is 1·0270.

In both the Atlantic and Pacific a local higher temperature is still found in the eastern equatorial regions of both oceans, but the increase from the lower temperature to the westward is now much less than it was at 100 fathoms, being only from 2° to 3° instead of 12° and 6°. With these reduced differences the specific gravity differences are also reduced.

Depth of 300 *Fathoms* (Map 5).—The mean temperature of the ocean at 300 fathoms is 44°·7, or 5°·4 less than at 200 fathoms. The higher temperature of the North as compared with the South Atlantic is even more pronounced than at less depths, as seen from a comparison of the regions of the two oceans included within the isothermal of 45°. Further, while the highest isothermal in the South Atlantic is 48°, covering a very small area, the same isothermal in the North Atlantic covers about half the area of the whole ocean, and includes two areas within which the temperature rises to fully 60°; in the western of the two it rises to 63°, or 15° higher than the highest temperature anywhere found in the South Atlantic. It is also to be noted that these two areas of warm water are both well to the west of the ocean, in other words, they

are in the lines of the drift of the surface currents. The highest isothermal in any other ocean is 53°, or 10° lower than that of the North Atlantic, thus emphatically distinguishing this ocean as, in this respect, markedly different from all other oceans.

The ten observed specific gravities in the Atlantic from lat. 13° to 40° N. give a mean of 1·0266, only one occurring as low as 1·0262 near Cape Verde Islands. In marked contrast with this, the mean of the fifteen specific gravities observed between lat. 10° and 40° S. is 1·0258, only one of which exceeded the minimum of the North Atlantic. Thus, we have still in the North Atlantic the specific gravities greatly more favourable to the descent of the warm water of the higher strata, and the observations of temperature amply show that this descent takes place.

A very different state of things now holds good in the Pacific Ocean, which in its western division has temperatures above the mean uninterruptedly through eighty degrees of latitude, and in its eastern division through forty degrees. As in the case of the Atlantic, the higher temperatures are in the western part of the ocean or in the lines of the warm surface currents. A lower temperature still prevails in mid-ocean immediately south of the equator, and from the western projection of this low temperature area to the south there is a somewhat rapid increase of temperature amounting at this depth to 5°. The two regions of highest temperature are 51° about ten degrees of latitude south of Japan, and 50° the same distance north of New Zealand.

The specific gravities, while still a little higher in the South than in the North Pacific, now approximate to each other over the whole extent of the ocean from lat. 30° N. to 40° S., the mean being 1·0256, very much below the specific gravity of the North Atlantic.

Depth of 400 *Fathoms* (Map 6).—The mean temperature of the ocean at 400 fathoms is 41°·8, or 2°·9 less than at 300 fathoms. The excess of temperature in the North Atlantic is even more pronounced than at the previous depth. In the South Atlantic the highest temperature is 42°·5, or only 0°·7 above the mean temperature of the whole ocean, but in the North Atlantic nearly the whole extent of it has a higher temperature than this, and the maximum temperature rises to 55°, or 12°·5 higher than in the South Atlantic. It is also to be noted that the higher temperatures still occupy the western division of the ocean.

The specific gravities of the two oceans are very different. In the North Atlantic the mean is 1·0264, but in the South Atlantic it is 1·0258, and in the Gulf of Guinea 1·0254. The densities thus favour the descent of the warmer water of the upper layers to greater depths in the North than in the South Atlantic.

In the North Pacific the highest isothermal is 43°, but in the South Pacific this isothermal covers a much wider extent, and temperature rises within the warm area to 47°, or 4° higher than in the North. In this part of the ocean the mean specific gravity is 1·0259, but elsewhere in the North and South Pacific it is only 1·0255.

There is still seen an increase, though it is now a small one, in the temperature of the Atlantic and Pacific in the extreme east of the equatorial region near the continents.

Depth of 500 *Fathoms* (Map 7).—Very marked changes have now been brought about in the distribution of temperature over the Atlantic. The mean temperature of the ocean has now fallen to 40°·1 or 1°·7 lower than at 400 fathoms, and the whole of the water of the South Atlantic is now under the average temperature of the whole ocean, except a narrow tongue which projects southward about long. 10° W. nearly as far as lat. 10° S., where a temperature of 40°·3 is found.

On the other hand, nearly the whole of the North Atlantic to the north of the line of lowest atmospheric pressure, marking the region of calms, is above the average, and the region of highest temperature is no longer located in the western division of the ocean in the line of the drift of the trades. But the highest temperature, 54°, is now to be found immediately to the west of Gibraltar, thus pointing to a new distinct source of the high temperature of the North Atlantic from 500 fathoms downwards.

The specific gravities of the North Atlantic are still much higher than any elsewhere observed, but at this depth there are no observations near Gibraltar. Those observed at greater depths will afterwards be referred to in connection with this appearance of high temperature in the east of the ocean.

No area indicating a region of higher temperature is now seen in the North Pacific, but in the South Pacific there is such a well-marked area between New Zealand and Australia, showing an isothermal of 44°, being thus 4° higher than the highest in the South Atlantic, but 10° lower than the highest in the North Atlantic. Observations of specific gravities at this depth are almost entirely wanting in the Pacific.

Depth of 600 *Fathoms* (Map 8).—The outstanding feature of the temperature at this depth is presented by the North Atlantic, where the higher temperatures no longer appear in the western part of the ocean. The highest isothermal seen anywhere, 51°, is to the west of Gibraltar, from which temperature gradually falls to 39° immediately off the coast of America. Between the Canaries and the Azores the specific gravity of 1·0267 has been observed, and a little to westward 1·0263. These are very high specific gravities for this depth, being much higher than any elsewhere observed in the ocean, and they point unmistakably to the warm dense undercurrent which issues from the Mediterranean as the source of the remarkably high temperature now overspreading the Atlantic. Further, the disposition of the isothermals alone would place the matter beyond dispute. The all but total absence of temperatures above the average from the South Atlantic is a noteworthy feature of this ocean, for only on its northern side does the temperature rise 0°·7 above the mean. This striking feature of the temperature of the South Atlantic, seen also at the depths immediately above and below the 600 fathoms depth, may be referred to two causes, the one being the transference to the

north of the equator of the high specific gravities of its upper layers, so that descent of the higher temperature is greatly retarded. The other cause is the greater depth to which these currents extend that have their origin in the trade winds of the South Atlantic, which, of all trade winds, are the strongest and most continuous.

The mean of twelve observations of specific gravity in the Gulf of Guinea is 1·0256, being thus markedly lower than the specific gravity observed to the west of the Canaries.

In the Pacific the highest temperatures are round the Galapagos Islands and to the north of New Zealand, where the temperature rises to 41°, being thus 10° lower than the highest in the North Atlantic. These positions accord with those of the highest temperature at less depth.

There is seen, just as at the 500 fathoms depth (Map 7), a local region of slightly lower temperature to the east of Australia between lat. 10° to 22° S. and long. 145° E. to 178° W. A better knowledge of the contours of the bed of the ocean and some knowledge of the distribution of specific gravities may be looked forward to as the explanation of this temperature.

Depth of 700 *Fathoms* (Map 9).—The mean temperature of the ocean at this depth is 38°·1, or 0°·9 lower than at 600 fathoms. The high temperature from the Straits of Gibraltar oceanwards is still the striking feature of the temperature. Though a comparatively high temperature still extends westwards to America, yet the high temperatures marking it out from the other oceans may be regarded as now restricted to the eastern half of the North Atlantic. The high specific gravity of 1·0268 has been recorded to the east of the Azores, whereas in the Gulf of Guinea, of the ten specific gravities observed by Mr Buchanan, the highest was 1·0260 and the mean of the whole 1·0255,—the high specific gravity of 1·0268 near the Azores thus still pointing to the denser warmer waters of the Mediterranean as their source. The relative distribution of the temperature in the South Atlantic and the Pacific remain substantially the same, and as regards the South Pacific even to a comparatively low temperature to the north-east of Australia.

It may be remarked that on nearing the Pacific coast of America in equatorial regions the temperature rises one degree, and in the Gulf of Guinea near the coast there is an increase of half a degree.

Depth of 800 *Fathoms* (Map 10).—The mean temperature of the ocean is 37°·3, or 0°·8 lower than at 700 fathoms. To the west of Gibraltar temperature has now fallen from 51° at 700 fathoms to 46°, but this region is still the source of an abnormally high temperature diffused westwards over the Atlantic, the great excess apparently not passing to the west of long. 30° W. At this depth a large number of specific gravities have been observed, chiefly by the Challenger. In the area of highest temperatures, 1·0268 and 1·0264 have been observed. In the Atlantic, from lat. 6° N. to 40° S., the mean of thirteen observed specific gravities is 1·0258, and in the Gulf of

Guinea five observations give a mean specific gravity of 1·0245. It is scarcely necessary to remark that these still point to the influence of the Mediterranean.

The temperature relations of the South Atlantic and the Pacific are unchanged. In the North Pacific ten observations give a mean specific gravity of 1·0255, and in the South Pacific fifteen observations also give a mean of 1·0255, which very well accords with the equable distribution of temperature over this ocean. The region of the low temperature to the north-east of Australia is only half a degree lower than surrounding temperatures.

Depth of 900 *Fathoms* (Map 11).—The mean temperature at this depth is 36°·8, having fallen half a degree from 800 fathoms. The highest temperature, 42°, is still to westward of Gibraltar, from which the temperature steadily falls westwards in the same manner as at the depths of 500, 600, 700, and 800 fathoms, but only to the extent of 2°. In the South Atlantic temperatures are relatively higher, and in the Pacific there is a tendency towards an equalised temperature more than in any of the other oceans. The high specific gravities of 1·0269 and 1·0264 were observed to the west and south-west of Gibraltar, which are not approached anywhere else, the highest of the thirteen observed between lat. 10° N. and 10° S. being 1·0259 and the mean 1·0256. It may be added that a specific gravity of 1·0271 has been recorded to the north-east of the Galapagos Islands in the region of the highest temperature of the Pacific at this depth.

Depth of 1000 *Fathoms* (Map 12).—From 900 to 1000 fathoms the mean temperature has only dropped 0°·3, being now 36°·5. The distribution of temperatures and specific gravities continues much the same over the oceans, the North Atlantic, looked at as a whole, showing the highest temperature, then follow in order the South Atlantic, the South Pacific, and finally the North Pacific.

There is still a trace seen of the influence of the Mediterranean. With respect to the high temperatures, so marked a feature of this part of the ocean from 500 to 1000 fathoms, it is to be remarked that they are not part and parcel of any great surface oceanic current, but simply an illustration of a slow vast movement of the waters of the ocean wholly due to differences of specific gravity of these waters.

Depth of 1500 *Fathoms* (Map 13).—From 1000 to 1500 fathoms temperature has fallen 1°·2, the mean being 35°·3. The highest temperatures are :—In the North Atlantic, 38° ; South Atlantic, 37°·5 ; North Pacific, 36°·5; and South Pacific, 36° ; there being now only 2° between the highest and lowest of these. A noticeable feature is that the North and South Atlantic have now nearly the same temperature. The western half of the Atlantic, from lat. 10° N. southwards, has a temperature decidedly lower than the eastern half.

But while the mean fall of the temperature of the whole ocean is only 1°·2, it is larger in the Atlantic. Thus averaging all the observations, the means of the North

Atlantic between latitudes 40° and 30° at depths of 1000 and 1500 fathoms are 39°·1 and 37°·4 ; and between the same two latitudes of the South Atlantic they are 37°·1 and 37°·0. Hence the temperature in the North Atlantic falls 1°·7, whereas in the South Atlantic the fall is only 0°·1. The following gives the results for both oceans from the equator to lat. 40° :—

	North Atlantic.	South Atlantic.
Mean Temperature at depth of 1000 fathoms, ...	39°·0	37°·8
Mean Temperature at depth of 1500 fathoms, ...	37°·3	37°·1
Differences,	1°·7	0°·7

The relatively slow rate of decrease of temperature of the South Atlantic may be regarded as commencing about 800 fathoms, to be clearly marked at 1000 fathoms, from which depth downwards it gradually approximates through 1100, 1200, 1300, and 1400 fathoms to what is shown at 1500 fathoms on Map 14. The specific gravities at the bottom of the ocean (Map 16) afford a ready explanation of this remarkable distribution of temperature. Owing to the higher specific gravities of the North Atlantic, an extensive deep-sea current from the North to the South Atlantic, carrying a higher temperature with it, sets in at depths at which the influence of the surface currents is no longer felt, and becomes more pronounced as the depth below 1000 fathoms is increased. Hence the North Atlantic receives large accessions to its salinity from the South Atlantic through the surface currents, which the deep-sea currents again return to the South Atlantic. It will be seen from Map 16 that this source of movement, viz., differences of specific gravities, is virtually absent from the deep waters of the Pacific.

The Gulf of Mexico.

This sea exhibits several peculiarities as regards temperature and specific gravity which have important bearings on oceanic circulation. The surface temperature of the southern half is above 80° and the northern half under it. The specific gravity in the south-eastern portion is 1·0271, rising in November to a mean of 1·0283, falling in the north of the Gulf to 1·0266. The high temperature and the specific gravity of the Gulf of Mexico is due to the circumstance that the strong current entering it from the east has had, during its passage across the Atlantic, its surface long exposed to a blazing sun and a dry, clear atmosphere. As there is no passage to westward for the current, the surface waters are further delayed in the Gulf till they escape into the Atlantic, chiefly through the Straits of Bemini.

At the 100 fathoms depth the temperature conditions have materially altered. As regards the entrance to the Gulf, it is within the North Atlantic isothermal of 65°, but over the Gulf itself temperature, to the west of long. 90° W., falls below 60°, and over a small region between that line and the continent it falls to 55°. Here, then, observation gives no evidence that the dense surface waters descend to any great depth carrying with them their high temperature downward. The evidence, on the contrary, goes to show that the strong surface current issuing through the Straits of Bemini, with the deeper current it generates, drains away, to a very large extent, the whole of the warm dense waters of the surface, thus bringing about an upwelling of colder water in the western part of the Gulf, so that the temperature there is 15° lower than it is immediately to the south-west of Cuba. Unfortunately, no specific gravities have been available at this and lower depths in the Gulf of Mexico, which would probably show a diminished specific gravity corresponding to the diminished temperature. Three specific gravities have, however, been observed in the western part of the Atlantic, viz., 1·0278, 1·0278 and 1·0274, which may be regarded as pointing to a mixing of the higher surface specific gravities of the Gulf of Mexico with the water of the Atlantic at this depth.

The relation of the temperature of the west of the Gulf of Mexico to that of the Atlantic continues to hold at greater depths till the temperature falls at 700 fathoms to 39°·5, at which depth the Gulf of Mexico becomes "a closed sea," and the temperature remains at this point down to the greatest depth, 2067 fathoms, of the Gulf of Mexico. The following gives a comparison of the lowest temperature in the Gulf of Mexico and the temperature at the entrance to the Gulf at the different depths :—

Depth in Fathoms.	Temperature at Entrance.	Lowest Temperature in Gulf.	Difference.
200	55°·0	46°·0	9°·0
300	50°·0	44°·0	6°·0
400	43°·5	41°·0	2°·5
500	41°·5	40°·0	1°·5
600	41°·0	40°·0	1°·0
700	40°·0	39°·5	0°·5

These facts point to a strong upwelling of the deep waters in the western division of the Gulf of Mexico, necessitated by the strong current which issues from it, and which extends to a considerable depth in the ocean. This view is borne out by the fact that the Atlantic easterly current is there embayed before starting to join the Atlantic north-eastern current on its way towards the Arctic Ocean, and southerly and south-westerly winds become prevalent, thus inducing upwelling in the western part of the Gulf.

It has been calculated that, owing to the heaping up of the waters driven by the

trade winds into the Gulf of Mexico, its level is thereby raised fully three feet above the general level of the ocean. The following peculiarities distinguish this remarkable current: at its starting place in the Gulf of Mexico its waters have a higher specific gravity than those of any other ocean current at its starting; it starts with a three-feet head of water; and along its whole course, from the Straits of Florida to the Arctic Ocean, the prevailing winds at all seasons are substantially south-westerly or in the same line of movement. Hence the volume and speed of this great ocean current as it issues from the tropical region, and the enormous influence it has on the western climates of Eurasia.

The Mediterranean Sea.

The mean annual surface isothermal of 65° from the Atlantic passes eastwards through the Strait of Gibraltar, curves round by the north of Sardinia, and round by the Strait of Messina to Cephalonia; and the isothermal of 70° passes from Libya in a north-easterly direction to Tarsus; and the isothermal of 60° just appears in the extreme north of the Gulf of Lyons.

To the west of the Strait of Gibraltar the specific gravity of the surface is a little higher than 1·0270, but it quickly increases in advancing eastwards till, about long. 10° E., it rises to 1·0280, and over the eastern basin of the sea it is 1·0290, showing thus a specific gravity higher than ever occurs in the open sea. Hence the water of the Mediterranean, even on the surface, is much salter than that of the Atlantic. This is due to the dry climate of the region, so that the loss from evaporation is not nearly compensated for by the fresh-water additions from the rainfall and by the rivers which empty themselves into its basin.

The observations and discussions of Dr Carpenter on this sea and the Atlantic adjoining in 1870–71 must be regarded as a classical contribution to the question of oceanic circulation. The results of these and other observations and discussions established the important fact that in the Strait of Gibraltar there are, after allowing for tidal influence, two currents, one superimposed on the other. The upper current is an inflowing one carrying with it the surface water of the Atlantic, and the undercurrent is an outflowing one, carrying out with it into the Atlantic the warmer and denser underlying water of the Mediterranean.

The submarine ridge at the Strait separating the deep water of the Atlantic from that of the Mediterranean is not quite 200 fathoms from the surface, and hence the direct communication between the seas is confined within that depth. A little way to the east of the Strait the temperature of the Mediterranean at 100 fathoms is about 55°; it increases eastward to 58° to the east of Malta, and rises a little above 60° in the Levant. The specific gravities to the east of the Strait are about 1·0284, whereas in the Atlantic to the west specific gravity is but 1·0267. Hence the outflowing undercurrent

throws into the Atlantic a body of water much salter, and therefore, even after allowing for temperature, much denser, than the water of that ocean.

At 200 fathoms to the east of the Strait the temperature is 55°, from which, on proceeding eastwards, it gradually rises to 57° about long. 20° E. and to 58° in the Levant. To the east of the Strait the specific gravity is now 1·0287, while a little to the west in the Atlantic it is 1·0268 ; in the Levant the specific gravity is 1·0290. At 300 fathoms, and down to the bottom of the sea, the temperature of the western basin is 55°·5 and of the eastern basin 56°·5 ; the mean specific gravity is 1·0290, calculated from the numerous observations made in the eastern basin by the "Pola" Expeditions in 1890–92. From the few deep-sea observations made of specific gravities in the western basin, it is probable that the mean there is about 1·0286. The greatest depth observed by the "Pola" was 4400 metres, or 2406 fathoms, in lat. 35° 45′ N. and long. 21° 46′ E., the temperature at that depth being 56°·3 and the specific gravity 1·0295. The above temperature is fully 20° higher than in the open ocean at that depth, and is closely approximate to the temperature of the Atlantic adjoining the Strait of Gibraltar at the depth of the ridge separating the two seas, or nearly 200 fathoms.

Owing to the great specific gravity of this warm undercurrent from the Mediterranean, it gradually sinks on entering the Atlantic, but its effect in heating the waters of this ocean over any considerable extent only becomes clearly apparent at the depth of 500 fathoms. Beyond this depth, its great influence is felt over nearly the whole breadth of the Atlantic to at least about 1000 fathoms. Periodical surveys of the Mediterranean would serve many important objects ; thus, if made every five years, it would soon be shown whether the outflow of the Gibraltar undercurrent of such high specific gravity is attended with any diminution of the salinity of this sea. It is therefore not winds and currents, but different specific gravities and different levels, which rule the interchanges of the waters of this sea.

The Red Sea.

The mean annual temperature of the surface waters near the head of the sea is 77° ; it rises to 80° about lat. 22° N., to 84° in lat. 16° N., and then drops down to 82° at the Straits. The isothermal of 80° is in long. 50° E.

At the Strait of Bab-el-Mandeb the specific gravity is 1·0275, which quickly increases on advancing northward to 1·0280, 1·0285, 1·0290, 1·0295, 1·0300, 1·0305, and near Suez to 1·031. These specific gravities are caused by the rapid evaporation which takes place on account of the great heat, dryness, and rainless character of the climate of this arm of the sea.

At 100 fathoms the temperature near the north end of the sea is 65°, from which

it gradually rises on proceeding southward to 75° near the Strait, outside which it quickly falls to 70° and 65° about long. 53° E. At this depth, in lat. 22° N., the specific gravity is 1·0302, immediately outside the Strait 1·0282, and off Socotra 1·0264. At 200 fathoms, and at greater depths, 200 fathoms being about the depth of the submarine ridge separating this sea from the ocean, the temperature is 71°. The specific gravity in lat. 22° N. is 1·0303, off Aden 1·0267, and near Socotra 1·0264, being thus nearly the same as the specific gravities at 100 fathoms. At 300 fathoms the specific gravity is 1·0303, and it is probable that this degree of salinity obtains down to the bottom of the sea.

An undercurrent of warm water of great saltness issues from the Red Sea, just as happens in the case of the Mediterranean, and, as will appear, it has a marked influence on the temperature and specific gravity of the north-western part of the Indian Ocean.

The Persian Gulf.

The mean annual surface temperature at the head of the Gulf is 80°; it rises to 82° a little to the west of Ormuz, and outside the Gulf falls to 80° in long. 60° E. In this last situation the specific gravity is 1·0271, but in the Gulf itself no specific gravities have been observed. Its influence, therefore, on the temperature of the Arabian Sea adjoining will be similar, though less in degree, to that of the Red Sea.

The Indian Ocean.

This ocean differs essentially from the other great oceans in being completely land-locked on its north side, in comparatively low latitudes, thus putting it, as a whole, more fully under the influence of the Southern Ocean, as will be seen as the lower depths are dealt with.

The most noticeable feature of the mean annual temperature of the surface is that the isothermals are more regularly distributed over the Indian Ocean than over any of the other oceans. From about lat. 13° S. to the north of the ocean the temperature exceeds 80°, except the north-west portion of the Arabian Sea, as shown on the map (Map 2). Over this tract temperature is lowered by the upwelling produced by the prevailing N.W. winds of that region, which consequently blow from the land seaward, driving the warm surface current before them, the place of the surface water being taken by the colder water rising from lower depths. This lowering is continued along the east coast of Africa to some distance south of Cape Guardafui. To the south of lat. 13° S. temperature falls with characteristic regularity as the latitude increases,

except that it is rather lower over the eastern parts off the coast of Australia than over the western parts off the coast of South Africa.

The specific gravities of the Arabian Sea and of the Bay of Bengal are strikingly different. Owing to the very salt currents from the Red Sea and Persian Gulf, and to the extreme dryness of the climate, the specific gravity of the Arabian Sea is large. On the other hand, owing to the heavy rainfall during the summer monsoon, and to the northerly winds during the winter months inducing upwelling, the specific gravity of the Bay of Bengal is low. For the same reasons the east coasts of Asia and the Eastern Archipelago are marked by a specific gravity much lower than anywhere else over the ocean in the same latitudes. The track of least specific gravity in the central part of this ocean is a little south of the equator from east to west.

At 100 fathoms a large extent of this ocean has a temperature above the mean (Map 3), this region being virtually defined by the isothermal of 60°. The highest temperature, 70°, is near the centre of the ocean, about long. 80° E. The same high temperature is found a little to the east of the Strait of Bab-el-Mandeb, from which point eastwards it gradually falls to 60°. The lowest temperature, 56°, overspreads a considerable area lying east and west to the south of Ceylon. This area lies in the region of the meeting of the N.E. and S.E. trades, and its position is analogous to the low-temperature regions of the Atlantic and Pacific at this depth with respect to the N.E. and S.E. trades of those oceans.

Unfortunately, at no depths north of lat. 40° S. are there any specific gravities available, except in the Arabian Sea and Bay of Bengal, and there only down to 400 fathoms. Outside the Strait of Bab-el-Mandeb the specific gravity is about 1·0280, but in the east of the Bay of Bengal it is 1·0259, or even lower, the temperatures being respectively 70° and 56°. The low specific gravities in the Bay of Bengal seriously prevent the diffusion downwards of the higher temperatures of the surface. In this region there is no doubt that upwelling takes place during the winter months when winds are northerly.

The distribution of temperature is totally changed at 200 fathoms, nearly the whole of the ocean north of lat. 40° S., being above 50°·1, the mean temperature of the oceans. The region of highest temperature, 61°, remains at the same place as at 100 fathoms, and the lowest temperature, 50°, is situated to the north-west of Australia, where also occurs at 100 fathoms a secondary minimum. The temperature is also high in the west of the Arabian Sea, and there the specific gravity is 1·0267 off Aden to the east of the Strait of Bab-el-Mandeb, gradually falling to 1·0261 near Ceylon.

At 300 fathoms the whole ocean is above the average temperature to the north of lat. 40° S., the absolute highest, 55°, being near Cape Guardafui. But the highest temperature in the ocean proper is 53°, the position of which is now fully ten degrees of longitude to the westwards of its position at 100 and 200 fathoms. This

temperature of 53° is now higher than any observed in the Pacific or South Atlantic, but is 10° lower than the highest in the North Atlantic near Bermuda. Again the lowest temperature, viz., 45°, is to the north of Australia, being only 0°·3 above the general mean.

At 400 fathoms the highest temperature continues to be found near Cape Guardafui, being, of course, due to the outflowing undercurrent from the Red Sea. The whole ocean is above the general mean, the lowest temperature being still to the north of Australia, but the highest, 50°, with the large extent of high temperature surrounding it, has now moved bodily a considerable distance to the south-west, so that the central position which, at 100 fathoms, was about lat. 18° S. and long. 90° E., is now in lat. 34° S. and long. 60° E.

From 500 to 800 fathoms substantially the same features characterise the temperature distribution of this ocean—a relatively high temperature in the Arabian Sea, another region of high temperature well to the south-west of the ocean, a region of lowest temperature between, extending from the north of Australia westwards, and a temperature much higher than is found in the Pacific or South Atlantic, but lower than the highest of the North Atlantic.

The high temperature of the Atlantic is mainly brought about by the large accessions of warm currents poured into it by the South Atlantic and the Mediterranean. But as regards the Indian Ocean, no such accessions from other oceans are received, with the exception of what is contributed by the Red Sea, and by a surface outflow from the Persian Gulf. Now these accessions cannot be regarded as influencing in any appreciable degree the region of high temperature near the centre of the ocean. This high temperature, as compared with the Pacific and South Atlantic, is in all probability due to the circumstance that for the heat generated on the surface in this intertropical region there is no escape to northward, but it is, on the contrary, all retained within the ocean itself.

At 900 and 1000 fathoms the Indian Ocean and South Atlantic have nearly the same temperature, both in this respect being intermediate between the North Atlantic on the one hand and the Pacific on the other.

At 1500 fathoms this is all reversed, the Indian Ocean being now the coldest ocean ; the larger portion is under the average, pointing out that, on account of the low surface specific gravity of this ocean taken as a whole, the higher temperature of the upper strata is not conveyed to such depths as occurs in the other oceans. Hence, at less depths, temperature is higher than would otherwise be the case. The highest temperature is in the north-west, about the region where, so far down as observations have been made, the specific gravity is great.

The Arctic Ocean (inclusive of the Norwegian Sea).

This ocean is bounded on the south by the Faroe Ridge, at a depth not exceeding 260 fathoms, extending from Iceland in a south-east direction to a point 45 miles south of Faroe. To this succeeds a deeper channel, the Wyville Thomson Ridge, 30 miles across, descending to 380 fathoms, on the east of which commences a shorter ridge, with a depth of 260 fathoms, connecting it with the mainland of Scotland. Since the shallowest part of the sea from Iceland to Greenland is less than 260 fathoms, it follows that this ocean is a "closed sea" at all depths greater than 260 fathoms, except for the short distance of 30 miles where the ridge sinks down to 380 fathoms.

Owing to the prevailing south-westerly winds and accompanying current, the isothermals of the surface of the sea from 60° to 45° are pushed to higher latitudes than anywhere else on the globe, and it is to be remarked that the isothermals of the surface water of the sea are, for the same positions, much higher than those for the air. The line of maximum temperature is not close to the coast, but lies out in the Atlantic a considerable way from the west coasts of Europe. The extension of the isothermal of 40° eastwards round the north of Norway, and of the isothermal of 30° northwards beyond Spitzbergen, are points of great interest in connection with the distribution of the isobars and prevailing winds of this region.

It is not only higher temperatures but also higher specific gravities that this great oceanic current conveys into high latitudes. Thus in the North Pacific the specific gravity of 1·0260 extends only to about lat. 33° N., and in the South Pacific, South Atlantic, and Indian Ocean it just passes lat. 40° S. in a few places. In the North Atlantic, however, it extends as far north as lat. 72° N. and the specific gravity of 1·0255 to lat. 78° N. This northern extension of the region of high temperature and specific gravity is doubtless occasioned by the complete absence of icebergs in the eastern division of this ocean. The important result is that the higher temperature of the surface descends to greater depths in this ocean than would otherwise be the case. The lowering of the specific gravities, by the rivers and rainfall, from the English Channel northwards along the west coast of Norway to Vardö is strongly marked.

It will be observed that at 100 fathoms there is an area to the south-west of Spitzbergen, extending as the depth increases, where the temperature is only 30°. This is the region where the prevailing winds, after curving round from the south-west to the north-east, sweep along the fields of Arctic ice, in relation to which the course of the isothermal of 35° is interesting. At this depth the highest temperature is close in shore to the eastward.

The specific gravities closely follow those of the surface. The mean of ten observations about lat. 73° N. and long. 0° to 40° E. is 1·0258, which is very greatly in excess of any specific gravity observed in any ocean in similar latitudes. These,

together with the extraordinarily high temperatures accompanying them, evidence the volume and depth of the powerful current from the Atlantic on which they depend.

At 200 fathoms this ocean is still in free contact with the Atlantic, and the higher temperatures are well inshore. The highest isothermal is 43° to the south of the Lofoten Isles, and it is remarkable that the isothermals of 35° and 30° are much in the same positions as at the 100 fathoms depth. The specific gravities are virtually identical with those at 100 fathoms, and at both depths they are highest midway between Norway and Spitzbergen.

Except the comparatively narrow channel of the Wyville Thomson Ridge, the whole of this ocean at 300 fathoms is cut off from the Atlantic and becomes a "closed sea," and as a consequence the temperature now assumes a wholly different mode of distribution. The isothermals, instead of having a S.W. and N.E. course on the lines of the great ocean current, indicate an area of higher temperature, with its axis approximately about lat. 70° N., extending nearly as far west as Jan Mayen, but between it and the Faroe Ridge there is a much lower temperature, 32°. Since in this cold area Mohn noted a specific gravity of 1·0262, the low temperature cannot be ascribed to upwelling, but its origin is rather to be referred to the north-west in the region marked out by the isothermal of 30°. The increase from 30° to 32° is derived from the upper denser waters, which, having passed the Faroe Ridge, have in their northerly course partially sunk to lower depths, and have consequently to some extent raised both the temperature and specific gravity.

The warmer area to the north-east, marked by the isothermals of 39°, 37° and 35°, is coincident with the region where the great south-westerly current comes to a stop and the north-easterly current begins its course. A head of water is no doubt formed in the region where these south-westerly winds and attendant currents cease. The additional pressure thereby produced, and the high specific gravities, result in a downward movement of the upper waters, and consequently the raising of the temperature over the region where it occurs. The increase of temperature from this strong downward movement is less and less as the depth increases, but it is distinctly traceable at least as far as 700 fathoms, and is still accompanied with the high specific gravities of the surface.

The positions of the isothermals from 300 to 700 fathoms make it plain that the movements of the ocean at these depths are strongly downwards rather than horizontal; that the influence of prevailing winds on the surface and deeper currents arising from them is no longer felt in any recognisable degree; and that all movements are virtually restricted to those caused by differences of temperature and salinity. The position retained by the region of higher temperature quite disproves the idea of the existence of any vorticose movement in these deep waters.

At 1000 fathoms and greater depths the temperature to the south-west of Spitz-

bergen falls to 29°. The deepest sounding made was 2005 fathoms in lat. 68° 21′ N. and long. 2° 5′ W., where the temperature observed was 29°·5. There are five positions, at depths exceeding 1500 fathoms, at which Mohn observed the temperature and specific gravity. They range from 1547 to 1861 fathoms, with a mean of 1688 fathoms; their mean position was lat. 69° 20′ N. and long. 3° 27′ E., and the mean temperature was 29°·8, and mean specific gravity 1·0259. This temperature found in the deepest parts of the Arctic Ocean is only from 2° to 3° higher than the freezing-point of sea-water of the above specific gravity. All the five positions underlie the region of the warm area, and it will be seen that the specific gravity there observed is closely approximate to that of the surface.

The area enclosed by the surface isothermal of 30° has virtually the same temperature down to the bottom, except that at the greater depths it falls to 29°, and the same area appears to have a lower specific gravity than the rest of this ocean, judging from the small number of observations of specific gravity taken. The important inference follows that the great volume of the warm dense current from the Atlantic does not contribute the water forming the north-easterly current that fills the cold area, but that it overspreads the region around where it terminates and thereafter descends downwards to greater depths, cooling as it descends till at about 1000 fathoms it becomes nearly as cold as the rest of the Arctic Ocean. The different specific gravities no doubt play an important part in delaying the mixture of these two great bodies of water placed side by side in the region enclosed between Norway, Iceland, Greenland, and Spitzbergen. The high specific gravities observed at the bottom doubtless play an important part in maintaining the fluidity of the bottom water of the Arctic Ocean.

The Southern Ocean.

Under this head all portions of the ocean to the south of lat. 40° S. are included. Everywhere in this extensive region the temperature of the surface falls below 60°. The lowest isothermal is 40°, which may be taken as the annual mean about lat. 55° S. all round the globe. To the south of lat. 55° S. no observations have been taken for any two or four months of the year, such as January and July, or February, May, August, and November, &c., from which a fairly good annual mean could be calculated. It is probable, however, that, reasoning from the positions of the isothermals of the air and the temperatures at 100 fathoms, an annual mean of about 30° encircles the globe near lat. 63° S. The specific gravity is under 1·0260 all round, falling to 1·0241 about lat. 65° S., this being the lowest specific gravity observed by the Challenger.

As regards the atmospheric pressure and the prevailing winds which necessarily result from the manner of its distribution, this ocean differs essentially from all other

oceans in presenting what is virtually an unbroken zone of water nearly as far south as the Antarctic Circle. Now from about lat. 30° S., where the highest atmospheric pressure of the southern hemisphere is massed, pressure falls from about 30·100 to 29·000 inches near lat. 63° S., from which it begins to rise as higher latitudes are reached, as shown by the prevailing winds. Over this vast region, more particularly from lat. 40° to 63° S., the prevailing winds all the year round are north-westerly and westerly. As the isobars are close to each other, these are high winds, and as they blow from lower to higher latitudes, in other words are constantly arriving into colder climates, they are accompanied with much rain, foul weather, and comparatively low surface specific gravities. The temperatures and specific gravities are further diminished by the melting of the ice, and of the icebergs so frequently met with in these seas.

The following table shows the mean specific gravities of the Pacific, Atlantic, and Indian Oceans from lat. 30° to 64° S. at depths of 100, 200, 300, 400, and 800 fathoms:—

	Pacific.		Atlantic.		Indian.	
	No. of Observations.	M. S. G.	No. of Observations.	M. S. G.	No. of Observations.	M. S. G.
100 fathoms . . .	14	1·0257	12	1·0261	5	1·0257
200 „ . . .	12	1·0255	11	1·0257	4	1·0256
300 „ . . .	12	1·0255	11	1·0256	3	1·0254
400 „ . . .	12	1·0255	12	1·0256	6	1·0255
800 „ . . .	10	1·0255	8	1·0257	...	...

The mean latitude of the Pacific and Atlantic observations is lat. 36° S., but of the Indian Ocean lat. 55° S. The specific gravities of the three oceans from 100 to 800 fathoms closely agree with each other, those for the South Atlantic being slightly greater. Here, then, there appears to be a total absence of such low specific gravities as have been observed by Mohn between Spitzbergen and Greenland, and by Makaroff, though at less depths, near the Sea of Okhotsk. The relatively high specific gravities maintained in the Southern Ocean, notwithstanding the heavy rainfall and extensive ice-melting over the surface and upper layers of the sea, must be attributed to the broad and powerful surface currents from the north-west, bringing with them the high temperature and specific gravity of sub-tropical regions, as already described.

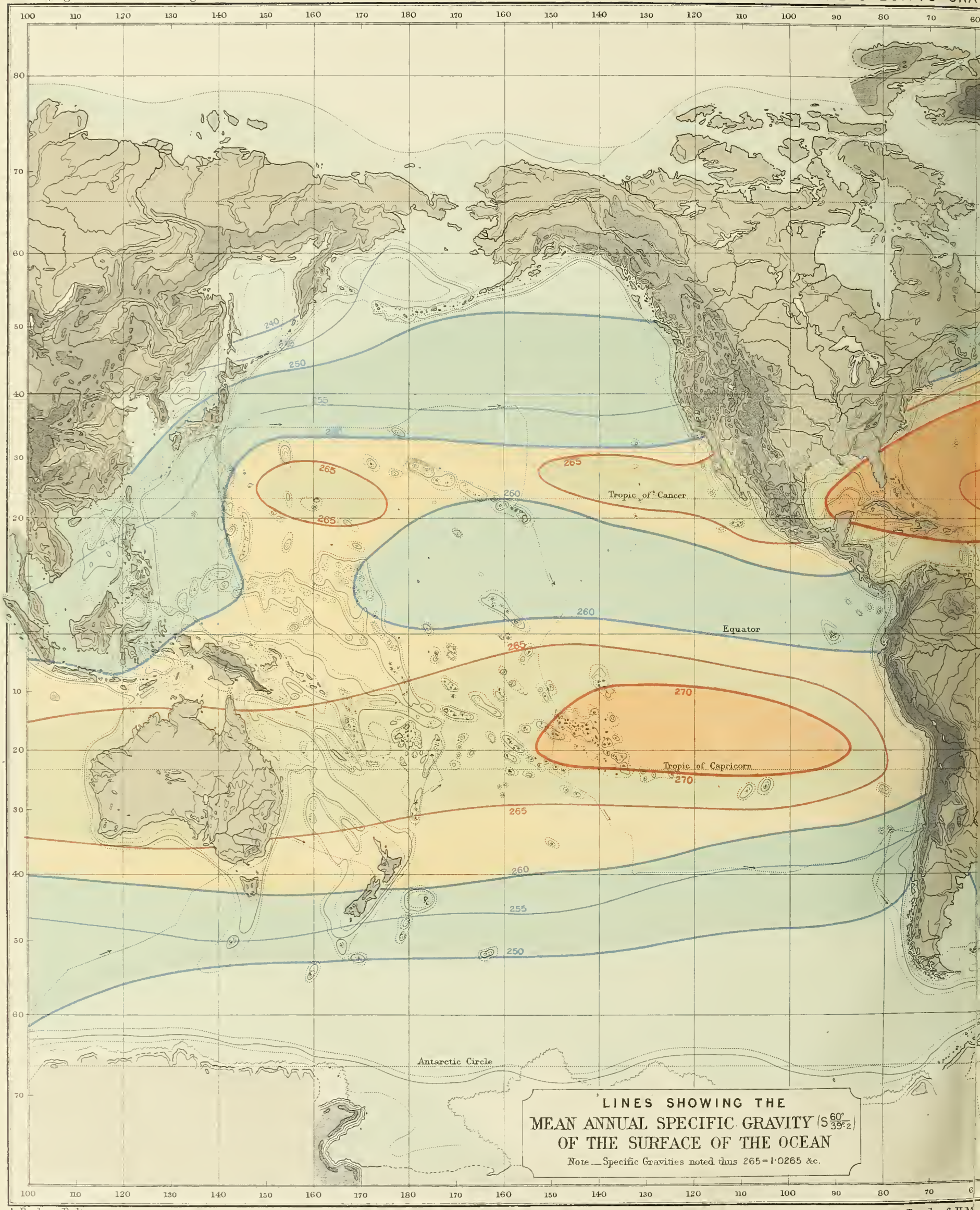
A map of the specific gravities at the bottom has been constructed (Map 16), a large number of such observations being available for the Report. The results for the three oceans south of lat. 30° S. are :—

	Number of Observations.	M. S. G.
Pacific, . . .	21	1·0258
Atlantic, . . .	20	1·0259
Indian Ocean, . .	13	1·0256

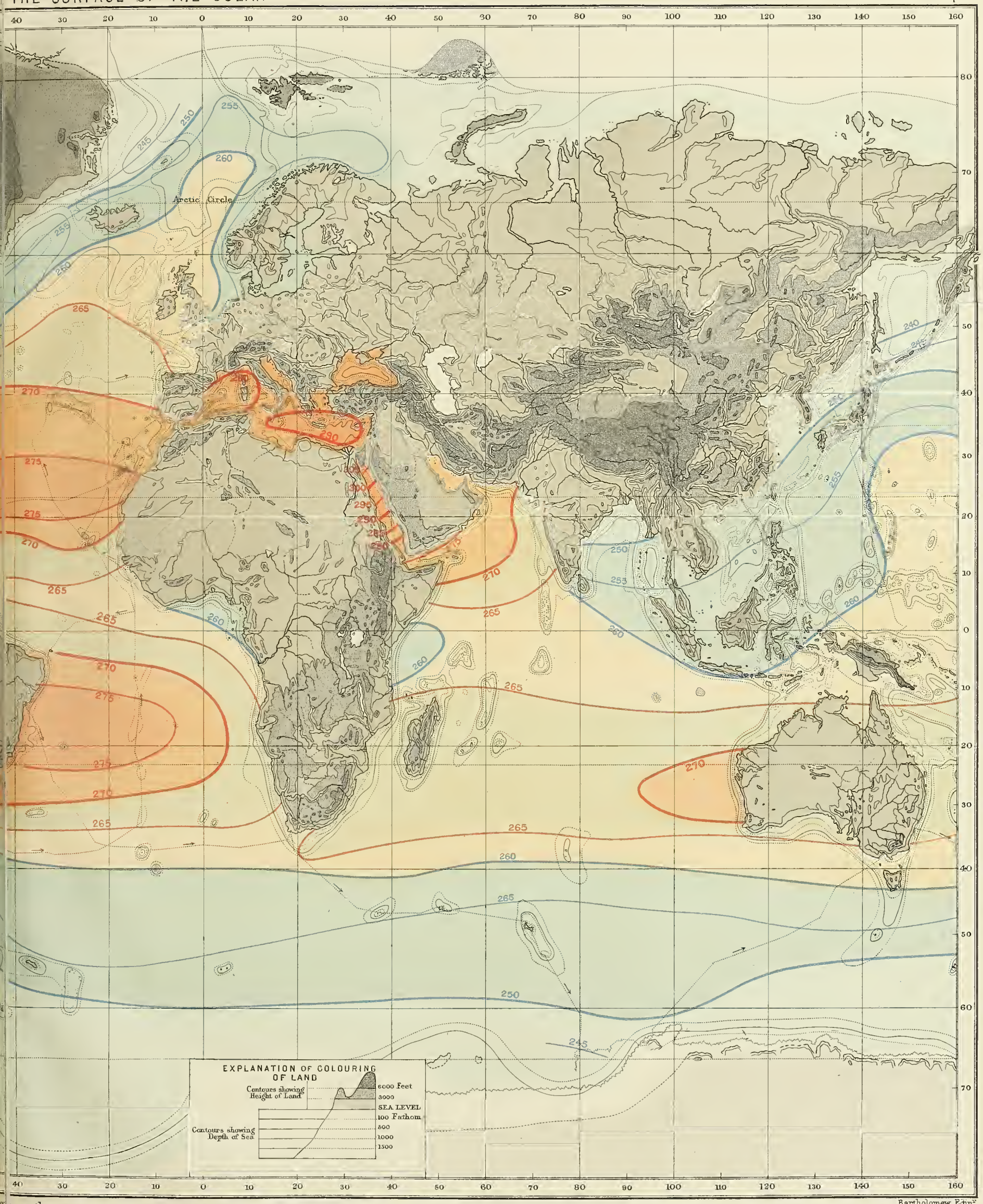
These, it will be seen, are all greater than the means of the five depths given above. The lower specific gravity of the Indian Ocean is due to the high latitudes in which they were observed by the Challenger. In the Atlantic, north of lat. 30° N., twenty-five observations give a mean of 1·0265. Hence even at the bottom of the ocean the North Atlantic continues to maintain a considerably higher specific gravity than any other ocean, and a higher temperature is carried down to the bottom. Similar results are shown by relatively high bottom specific gravities from Australia eastwards to long. 150° W. between Galapagos and Panama, and to the east of Brazil, which are immediately connected with the higher specific gravities and accompanying higher temperatures at different depths of these respective regions.

The close connection here indicated between the specific gravities and temperatures of the surface and the specific gravities and temperatures of the whole ocean down to the bottom, renders it difficult to overestimate the importance, in the further prosecution of this inquiry, of a correct knowledge of the mean annual specific gravity of the surface of the ocean, calculated from good monthly means which seldom appear in such publications. It is from such means, along with the corresponding means of the annual temperature of the surface, that the discussion must proceed.

MEAN ANNUAL SPECIFIC GRA



A. Buchan Delt.



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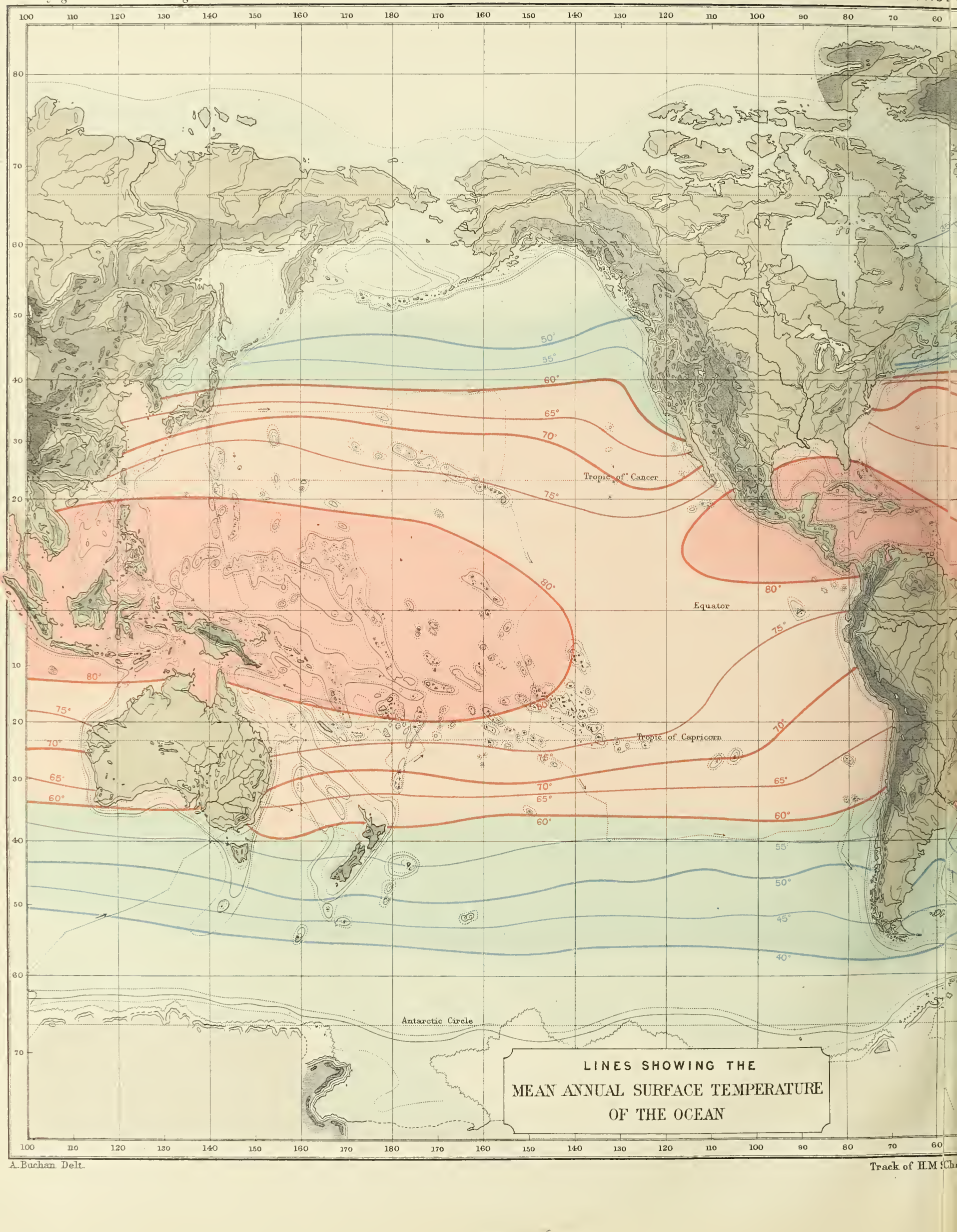
MEAN ANNUAL SURFACE



A. Buchan Delt.

Track of H.M.S Ch

Arctic Circle

EXPLANATION OF COLOURING OF LAND

Contours showing Height of Land

6000 Feet
3000
SEA LEVEL
100 Fathoms

Contours showing Depth of Sea

500
1000
1500

shown thus . . . .

Bartholomew, Edin.r

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NATURAL HISTORY

MEAN TEMPERATURE OF THE OCEAN

Tropic of Cancer

Equator

Tropic of Capricorn

Antarctic Circle

ISOTHERMAL LINES
SHOWING THE MEAN TEMPERATURE (FAHR)
OF THE OCEAN AT
DEPTH OF 100 FATHOMS

A. Buchan Delt.

Isothermals above Average shown in Red thus ——

Track of H.M.S. Challenger

T DEPTH OF 100 FATHOMS = 60°·7

Arctic Circle

EXPLANATION OF COLOURING

Contours showing Height of Land: 6000 Feet, 3000

SEA LEVEL

Contours showing Depth of Sea: 100 Fathoms, 600, 1000, 1500

own thus .....

Isothermals below Average shown in Blue thus ———

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MEAN TEMPERATURE OF THE OCEAN

Tropic of Cancer

Equator

Tropic of Capricorn

Antarctic Circle

ISOTHERMAL LINES
SHOWING THE MEAN TEMPERATURE (FAHR.)
OF THE OCEAN AT
DEPTH OF 200 FATHOMS

A. Buchan Delt.

Isothermals above Average shown in Red thus ——

Track of H.M.S. Cha

shown thus .....

Isothermals below Average shown in Blue thus _____

Bartholomew, Edin.r

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NATURAL HISTORY.

MEAN TEMPERATURE OF THE OCEAN

Tropic of Cancer

Equator

Tropic of Capricorn

Antarctic Circle

ISOTHERMAL LINES
SHOWING THE MEAN TEMPERATURE (FAHR)
OF THE OCEAN AT
DEPTH OF 300 FATHOMS

A. Buchan Delt.

Isothermals above Average shown in Red thus ——

Track of H.M.S. Chall

Arctic Circle

EXPLANATION OF COLOURING

Contours showing Height of Land

6000 Feet
3000
SEA LEVEL

Contours showing Depth of Sea

100 Fathoms
500
1000
1500

shown thus .....

Isothermals below Average shown in Blue thus ———

Bartholomew, Edinr

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NATURAL HISTORY

MEAN TEMPERATURE OF THE OCEAN

Tropic of Cancer

Equator

Tropic of Capricorn

Antarctic Circle

ISOTHERMAL LINES
SHOWING THE MEAN TEMPERATURE (FAHR)
OF THE OCEAN AT
DEPTH OF 400 FATHOMS

A. Buchan Delt.

Isothermals above Average shown in Red thus ——

Track of H.M.S. Che

Arctic Circle

EXPLANATION OF COLOURING

Contours showing Height of Land

6000 Feet
3000
SEA LEVEL

Contours showing Depth of Sea

100 Fathoms
500
1000
1500

shown thus

Isothermals below Average shown in Blue thus ———

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NATURAL HISTORY

MEAN TEMPERATURE OF THE OCEAN

Tropic of Cancer

Equator

Tropic of Capricorn

Antarctic Circle

ISOTHERMAL LINES
SHOWING THE MEAN TEMPERATURE (FAHR.)
OF THE OCEAN AT
DEPTH OF 500 FATHOMS

A. Buchan Delt.

Isothermals above Average shown in Red thus ——

Track of H.M.S. Ch

Arctic Circle

EXPLANATION OF COLOURING

Contours showing Height of Land

6000 Feet
3000
SEA LEVEL

Contours showing Depth of Sea

100 Fathoms
500
1000
1500

r shown thus .....

Isothermals below Average shown in Blue thus _____

Bartholomew, Edin.ʳ

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NATURAL HISTORY.

MEAN TEMPERATURE OF THE OCEA

100 110 120 130 140 150 160 170 180 170 160 150 140 130 120 110 100 90 80 70 60

80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70

36 33 36 39° 40 40° 40° 41° 42° 41° 40° 40° 39° 40° 39° 38 38 36°

Tropic of Cancer

Equator

Tropic of Capricorn

Antarctic Circle

ISOTHERMAL LINES
SHOWING THE MEAN TEMPERATURE (FAHR)
OF THE OCEAN AT
DEPTH OF 600 FATHOMS

100 110 120 130 140 150 160 170 180 170 160 150 140 130 120 110 100 90 80 70 60

A. Buchan Delt.

Isothermals above Average shown in Red thus ——

Track of H.M.S. Ch

Arctic Circle

EXPLANATION OF COLOURING

Contours showing Height of Land: 6000 Feet, 3000, SEA LEVEL

Contours showing Depth of Sea: 100 Fathoms, 500, 1000, 1500

shown thus

Isothermals below Average shown in Blue thus ——

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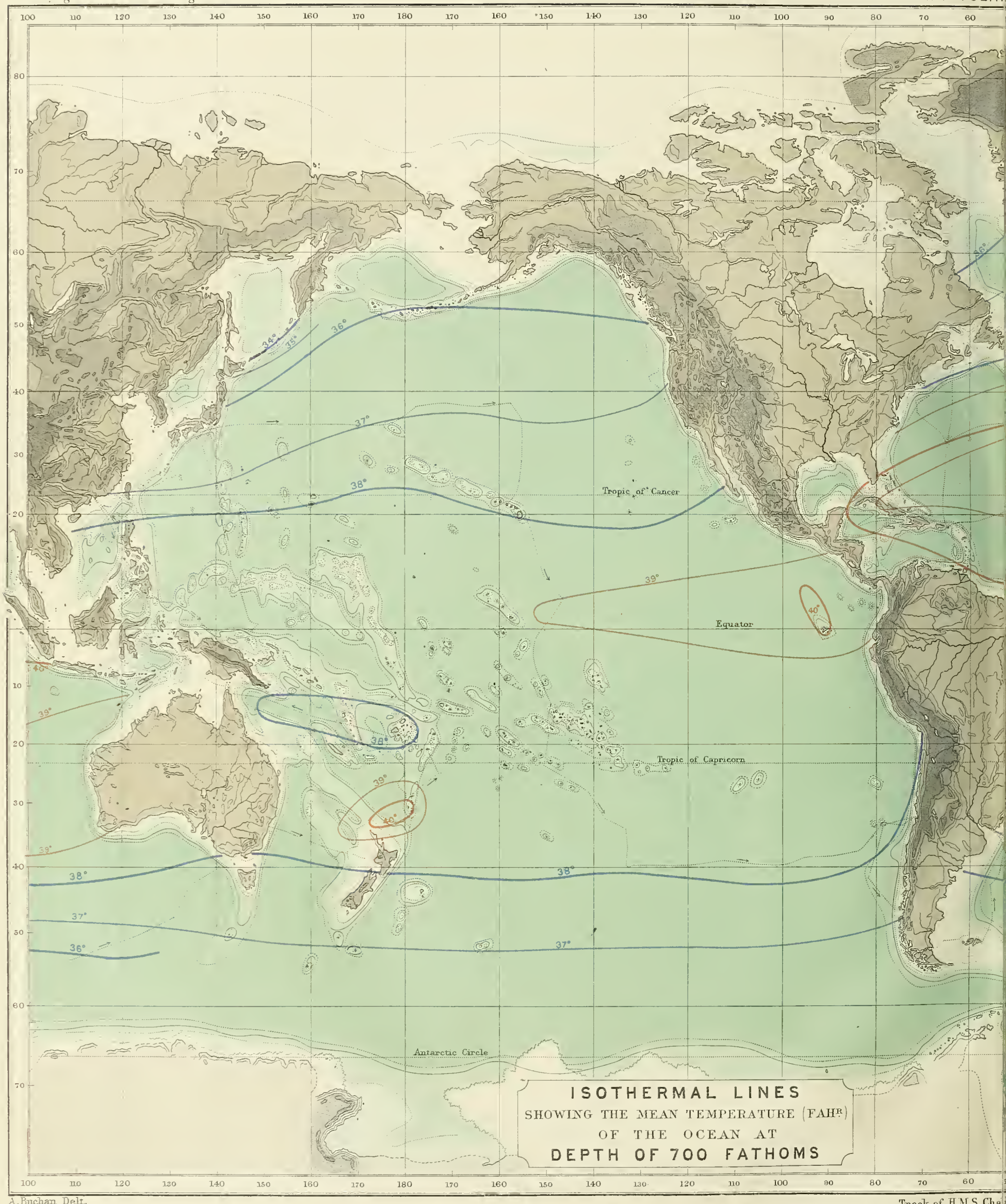
ZOOLOGY

MEAN TEMPERATURE OF THE OCEAN



ISOTHERMAL LINES

SHOWING THE MEAN TEMPERATURE (FAHR)

OF THE OCEAN AT

DEPTH OF 700 FATHOMS

A. Buchan Delt.

Isothermals above Average shown in Red thus ——

Track of H.M.S. Cha

Arctic Circle

EXPLANATION OF COLOURING

Contours showing Height of Land

6000 Feet
3000
SEA LEVEL

Contours showing Depth of Sea

100 Fathoms
500
1000
1500

r shown thus .....

Isothermals below Average shown in Blue thus _____

Bartholomew, Edinr

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NATURAL HISTORY

MEAN TEMPERATURE OF THE OCEAN

A. Buchan Delt.

Isothermals above Average shown in Red thus ———

Track of H.M.S. Cha

Arctic Circle

EXPLANATION OF COLOURING

Contours showing Height of Land: 6000 Feet, 3000, SEA LEVEL

Contours showing Depth of Sea: 100 Fathoms, 500, 1000, 1500

r shown thus

Isothermals below Average shown in Blue thus ———

Bartholomew, Edin.ʳ

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NATURAL HISTORY

MEAN TEMPERATURE OF THE OCEAN

100 110 120 130 140 150 160 170 180 170 160 150 140 130 120 110 100 90 80 70 60

80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70

34° 35° 36° 36°5 37° 38° 36° 40° 38° Equator 37° 38° 37° 37° 36°

Tropic of Cancer

Tropic of Capricorn

Antarctic Circle

ISOTHERMAL LINES
SHOWING THE MEAN TEMPERATURE (FAHR.)
OF THE OCEAN AT
DEPTH OF 900 FATHOMS

100 110 120 130 140 150 160 170 180 170 160 150 140 130 120 110 100 90 80 70 60

A. Buchan Delt.

Isothermals above Average shown in Red thus ——

Track of H.M.S. Ch

Arctic Circle

30°

38°

39°

40°

39°

39°

38°

38°

37°

37°

36°

36°

34°

36°

36°5

37°

37°

EXPLANATION OF COLOURING

Contours showing Height of Land

6000 Feet
3000
SEA LEVEL

Contours showing Depth of Sea

100 Fathoms
500
1000
1500

er shown thus .....

Isothermals below Average shown in Blue thus ———

Bartholomew, Edinr

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NATURAL HISTORY

MEAN TEMPERATURE OF THE OCEAN

100 110 120 130 140 150 160 170 180 170 160 150 140 130 120 110 100 90 80 70 60

80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70

34° 36° 34° 35° 36°

Tropic of Cancer

36·5 36·5

Equator

37° 37·5 37° 37°

Tropic of Capricorn

38° 37° 37° 36·5 36°

Antarctic Circle

ISOTHERMAL LINES

SHOWING THE MEAN TEMPERATURE (FAHR.)
OF THE OCEAN AT
DEPTH OF 1000 FATHOMS

100 110 120 130 140 150 160 170 180 170 160 150 140 130 120 110 100 90 80 70 60

A. Buchan Delt.

Isothermals above Average shown in Red thus ——

Track of H.M.S. Chall

shown thus . . . . . *Isothermals below Average shown in Blue thus* ——

Bartholomew, Edin.ʳ

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NATURAL HISTORY
Z 22 D

MEAN TEMPERATURE OF THE OCEAN

ISOTHERMAL LINES
SHOWING THE MEAN TEMPERATURE (FAHR)
OF THE OCEAN AT
DEPTH OF 1500 FATHOMS

A. Buchan Delt.

Isothermals above Average shown in Red thus ——

Track of H.M.S. Chal

er shown thus .....

Isothermals below Average shown in Blue thus

Bartholomew, Edin.ʳ

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NATURAL HISTORY
Z 22 D

MEAN TEMPERATURE OF THE OCEAN

Tropic of Cancer

Equator

Tropic of Capricorn

Antarctic Circle

FIGURES SHOWING THE MEAN TEMPERATURE OF THE OCEAN AT DEPTH OF 2200 FATHOMS

Note:—Red Figures show the Excess above 35°·2
Blue Figures show the Defect below 35°·2

A. Buchan Delt.

Track of H.M.S. Chall

Arctic Circle

EXPLANATION OF COLOURING

Contours showing Height of Land: 6000 Feet, 3000, SEA LEVEL

Contours showing Depth of Sea: 100 Fathoms, 500, 1000, 1500

r shown thus .....

Bartholomew, Edinr

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NATURAL HISTORY
Z 24 D